

Particle Distributions and Correlations in ATLAS

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On behalf of the ATLAS Collaboration

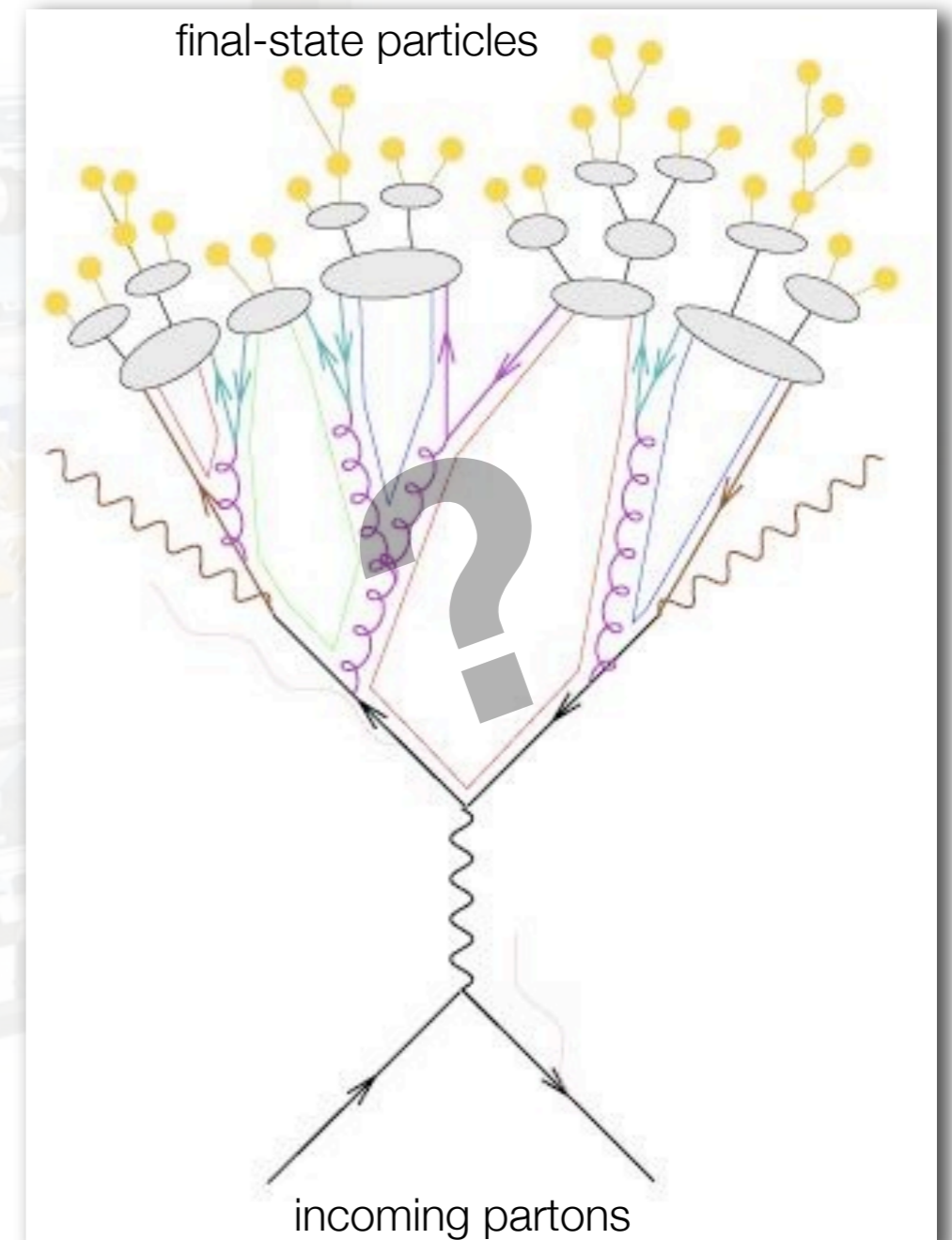
Outline

- Motivation
- Data Samples and Event Selection
- Correlations in ATLAS:
 - $\Delta\phi$ Correlations
<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-082/>
 - Inclusive Two-Particle Angular Correlations
- Summary

Not discussed here

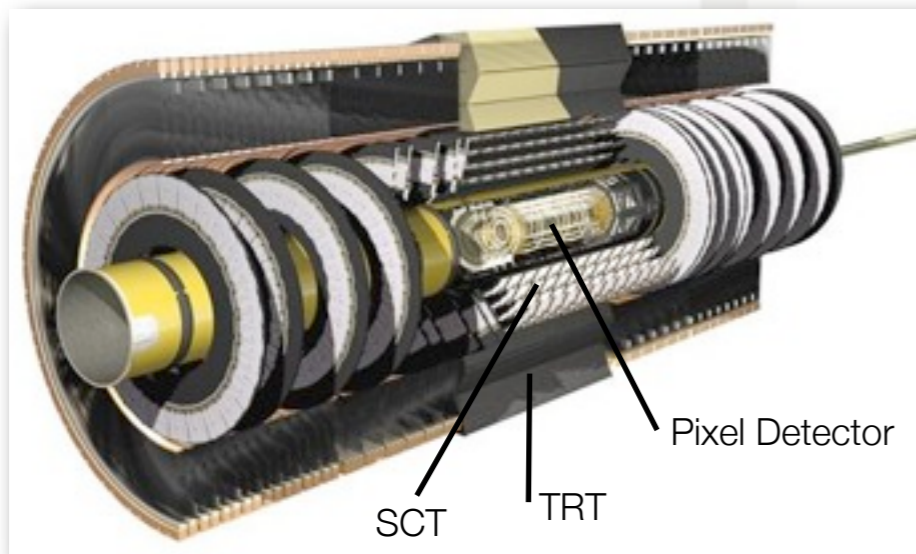
Motivation

- Models to describe dynamics of multi-particle production are incomplete: limited explanation of emission of soft radiation.
- Study of correlations between final state particles allows us to investigate the underlying mechanisms of particle production at LHC energies.
- Identify important dynamical information that can be incorporated in models to gain a better and more global picture (tuning).



Data Samples and Event Selection

The data samples used in this analysis:



Energy	Integrated Luminosity
900 GeV	$7 \mu\text{b}^{-1}$
7 TeV	$190 \mu\text{b}^{-1}$

Limited dataset, low luminosity, low pile-up

- ATLAS Inner Detector fully operational and solenoid at 2T,
- triggered by a single-arm, level 1 Minimum Bias Trigger Scintillator,
- at least one primary vertex,
- if there is a second vertex it should not be associated to more than four tracks (to remove events with more than one interaction per bunch crossing),
- to contain at least **two** tracks in the phase-space:
 - $p_T > 100 \text{ MeV}$
 - $|\eta| < 2.5$

Event Requirements

Same as minimum bias analysis - H. Schulz talk



Inclusive Two-Particle Angular Correlations

ATLAS Note:

“Measurement of Inclusive Two-Particle Angular Correlations in Proton-Proton Collisions at $\sqrt{s} = 900 \text{ GeV}$ and 7 TeV ”

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-055/>

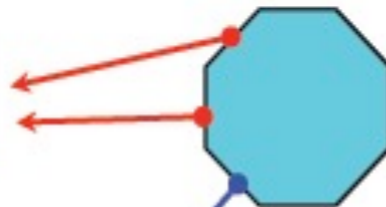
Analysis Overview

The inclusive two-particle angular correlation function is given by:

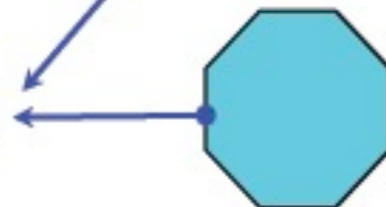
$$R(\Delta\eta, \Delta\phi) = \frac{\langle (N_{ch} - 1) F(N_{ch}, \Delta\eta, \Delta\phi) \rangle_{ch}}{B(\Delta\eta, \Delta\phi)} - \langle N_{ch} - 1 \rangle_{ch}$$

where $\langle \dots \rangle_{ch}$ indicates an average over contributions from all particle multiplicities.

Foreground: $F_n(\Delta\eta, \Delta\phi)$
(correlated + uncorrelated pairs):



Background: $B_n(\Delta\eta, \Delta\phi)$
(uncorrelated pairs):



Correlations between emissions in a single event. Normalised by the total number of events.

Distribution of uncorrelated pairs. Particle pairs made from independent events. Normalised by its integral.

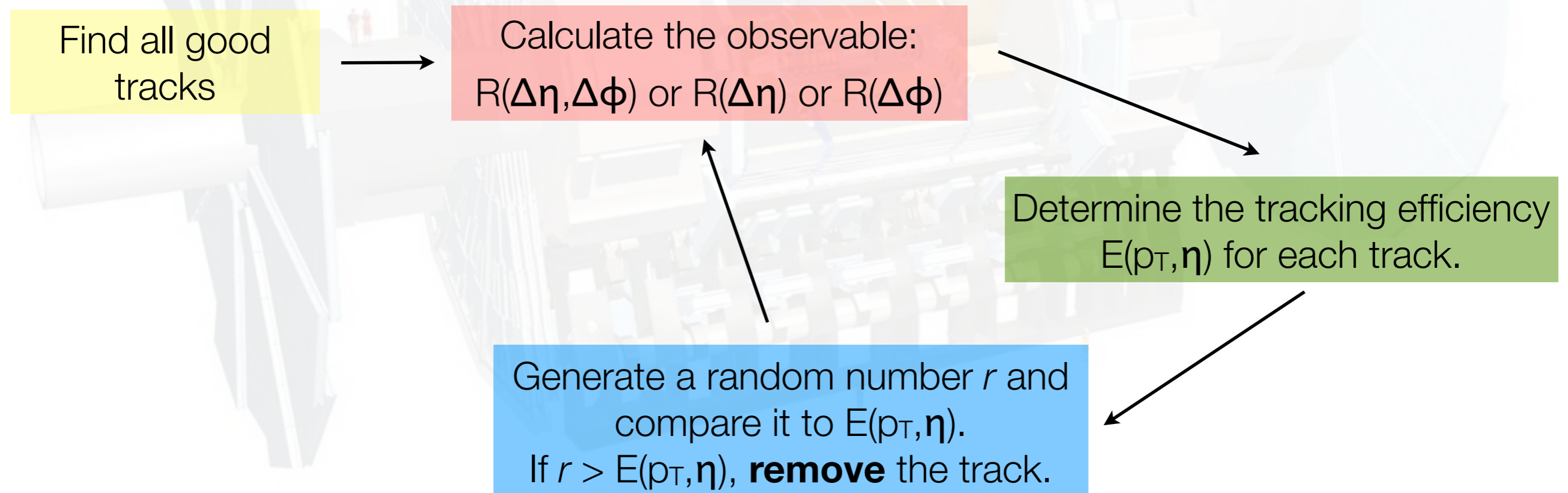
N_{ch} is the average particle multiplicity.

Correction Procedure

To account for inefficiencies in the **vertex and trigger selection**, the foreground and multiplicity distributions were weighted event-by-event with:

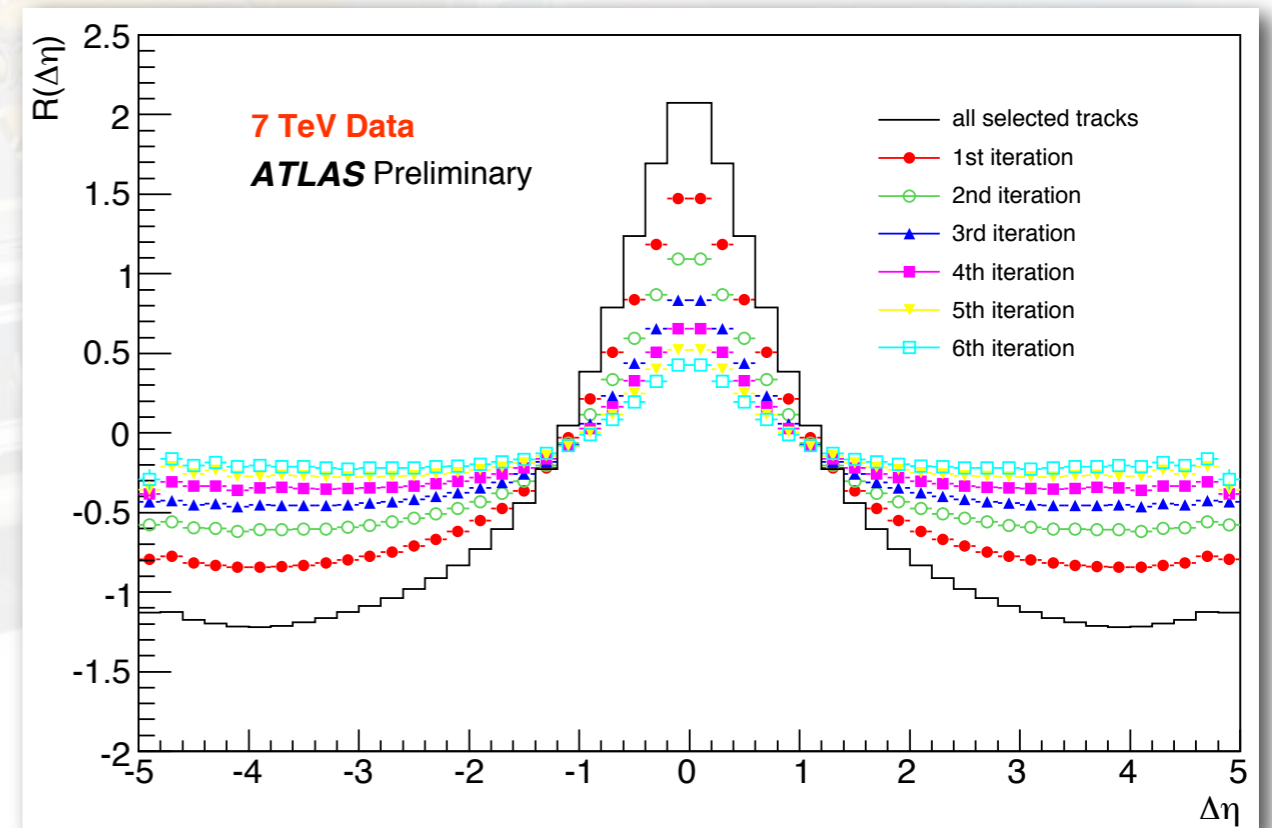
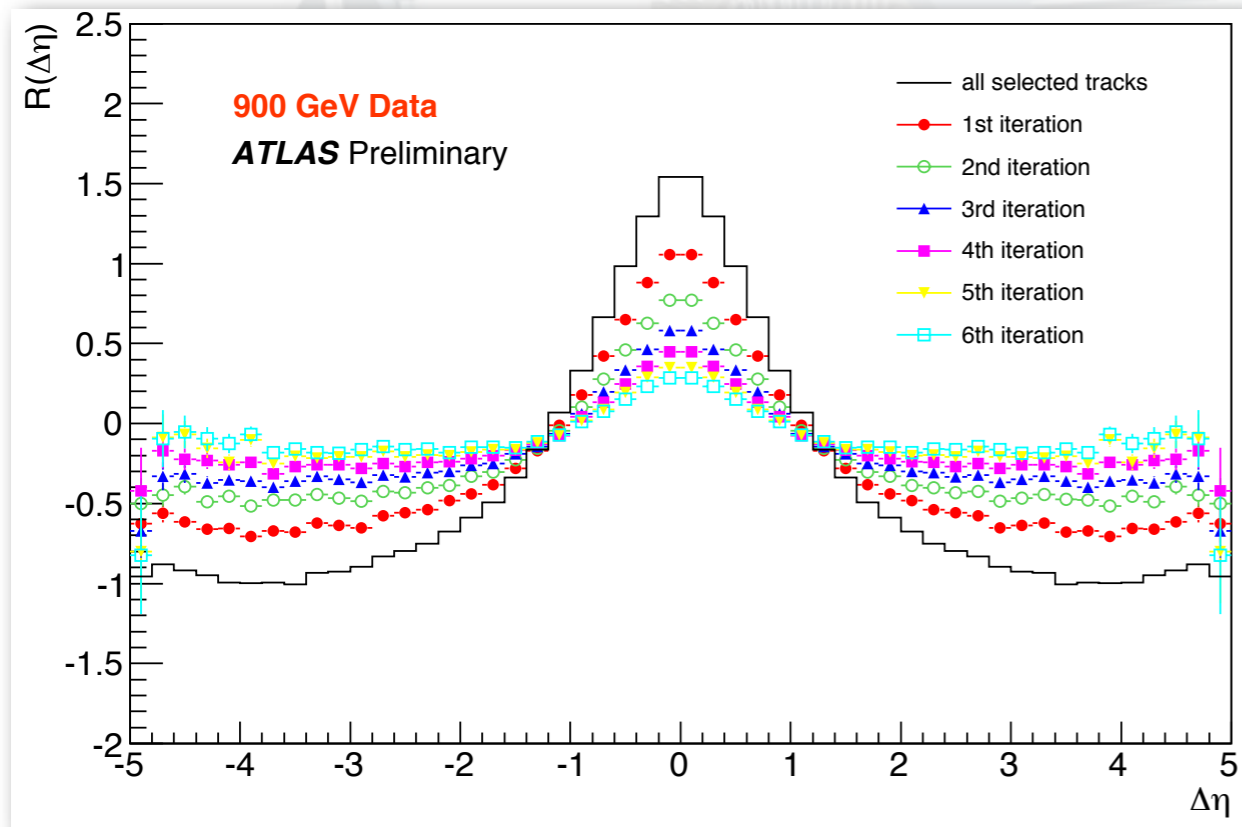
$$w_{ev}(n_{sel}^{BS}) = \frac{1}{\epsilon_{trig}(n_{sel}^{BS})} \frac{1}{\epsilon_{vtx}(n_{sel}^{BS})}$$

The effect of tracking inefficiencies is corrected for using a **data-driven** method.



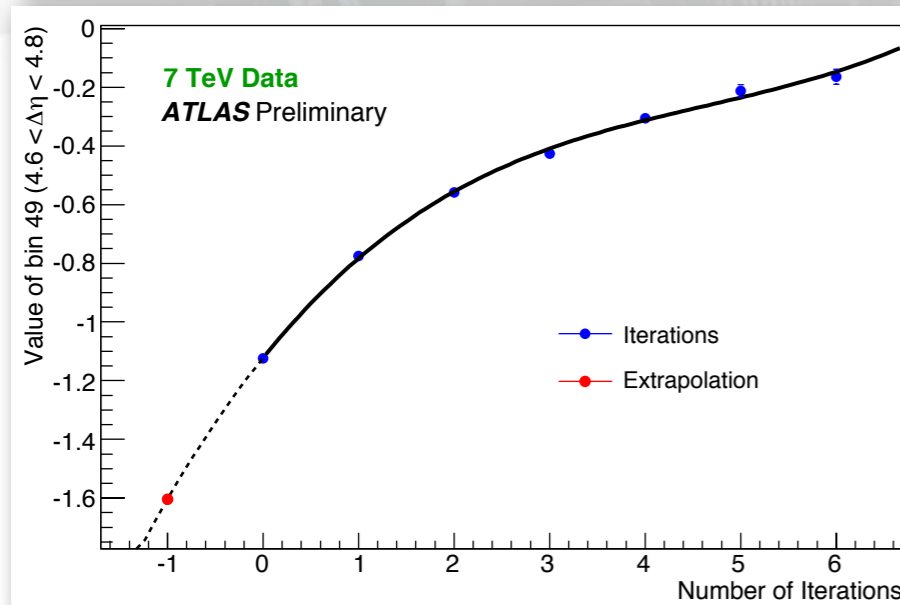
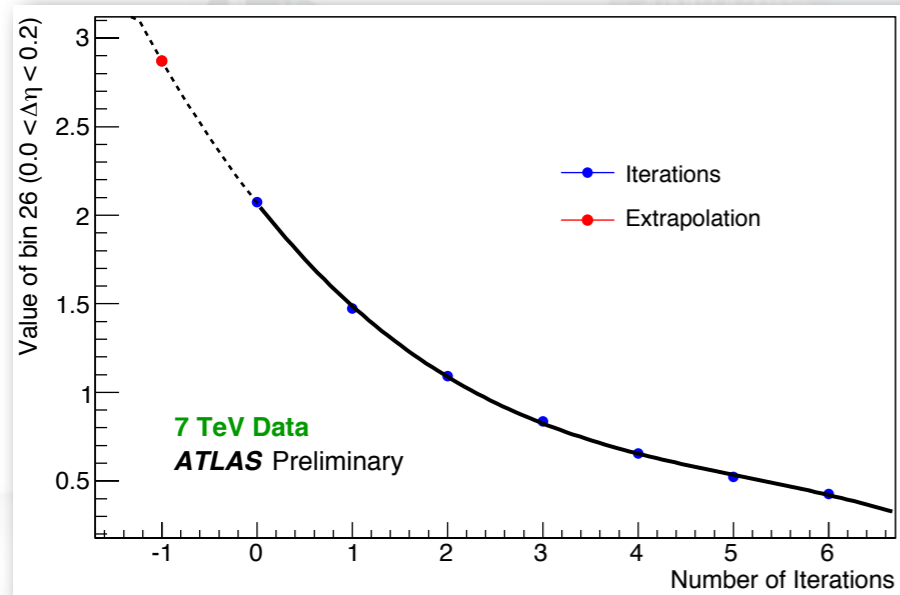
Correction Procedure

Each iteration corresponds to an additional application of the detector effect on the data. The **-1 iteration** corresponds to the observable when **no detector effects** are present.

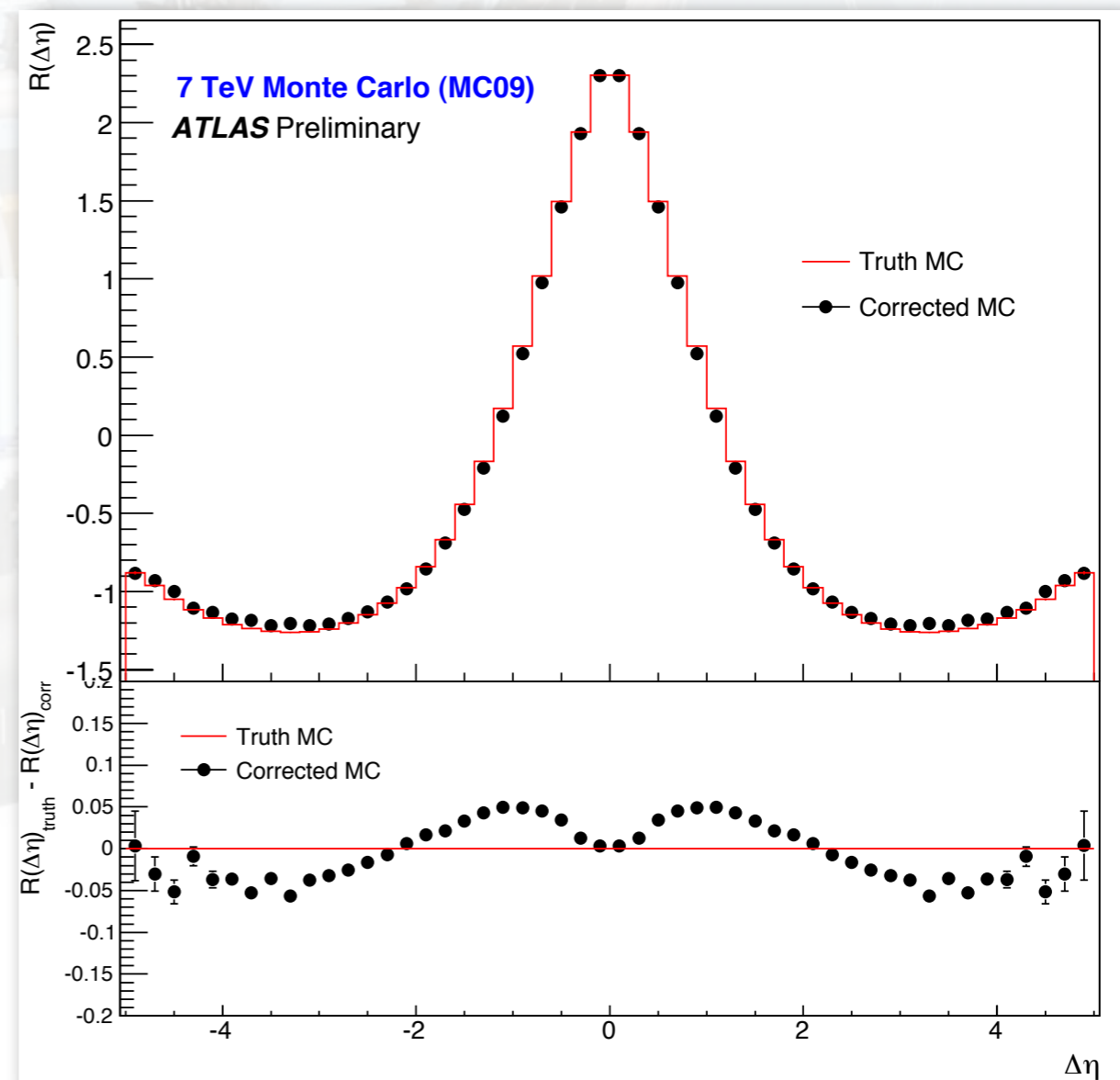


Correction Procedure

The value of (each bin of) the observable is plotted as a function of the iteration number (0, 1, ..., N) and fitted using a **third-degree polynomial**. By extrapolating this fit to -1, an estimate of the true value can be made.



Testing method in Monte Carlo:



Statistical and Systematic Uncertainties

I. Extrapolation to $N=-1$

The statistical error in the corrected value will be the result of propagating the statistical uncertainties in the parameters of the fit.

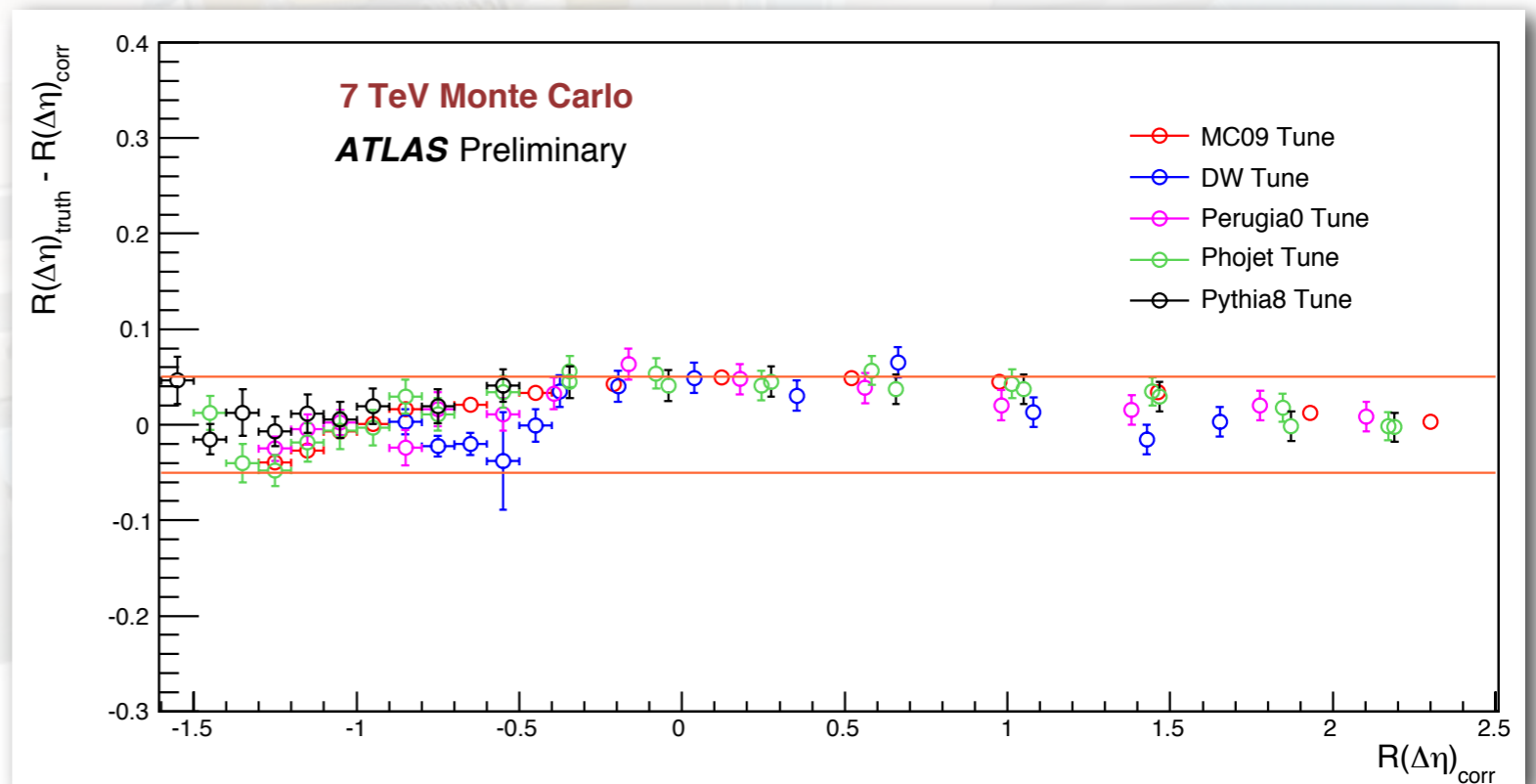
II. Uncertainties on the Efficiencies

Determined by varying the efficiencies up or down and propagating through the analysis.

III. Non-closure in Monte Carlo

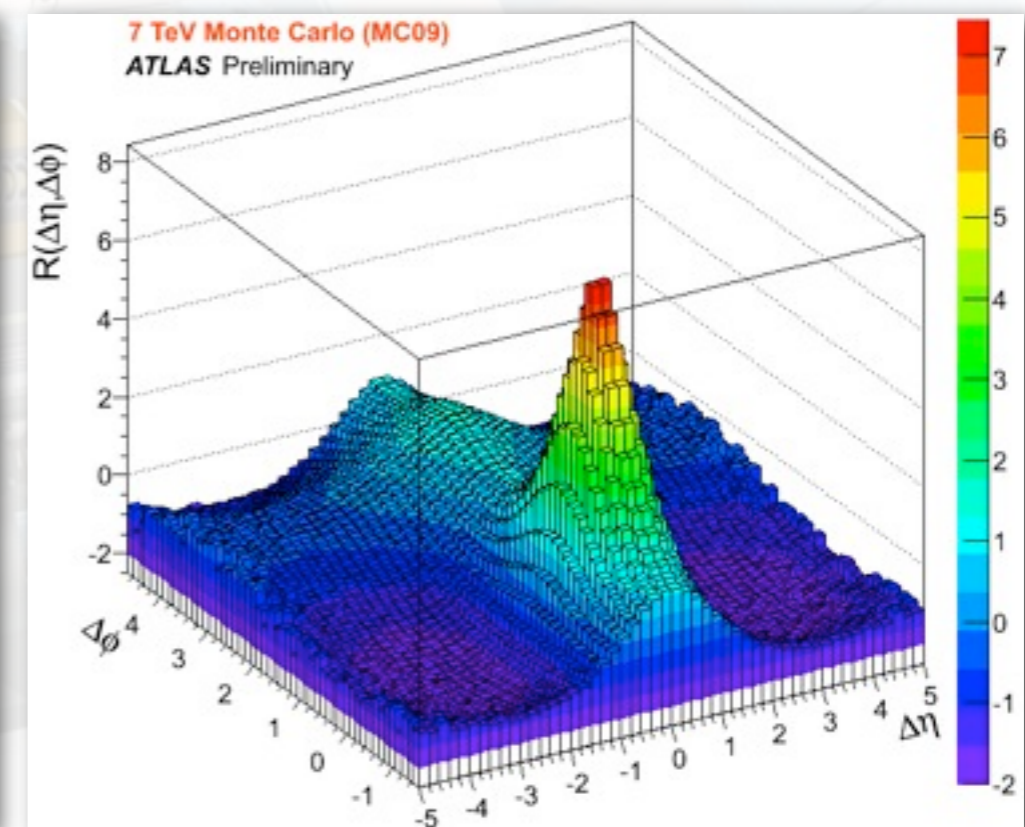
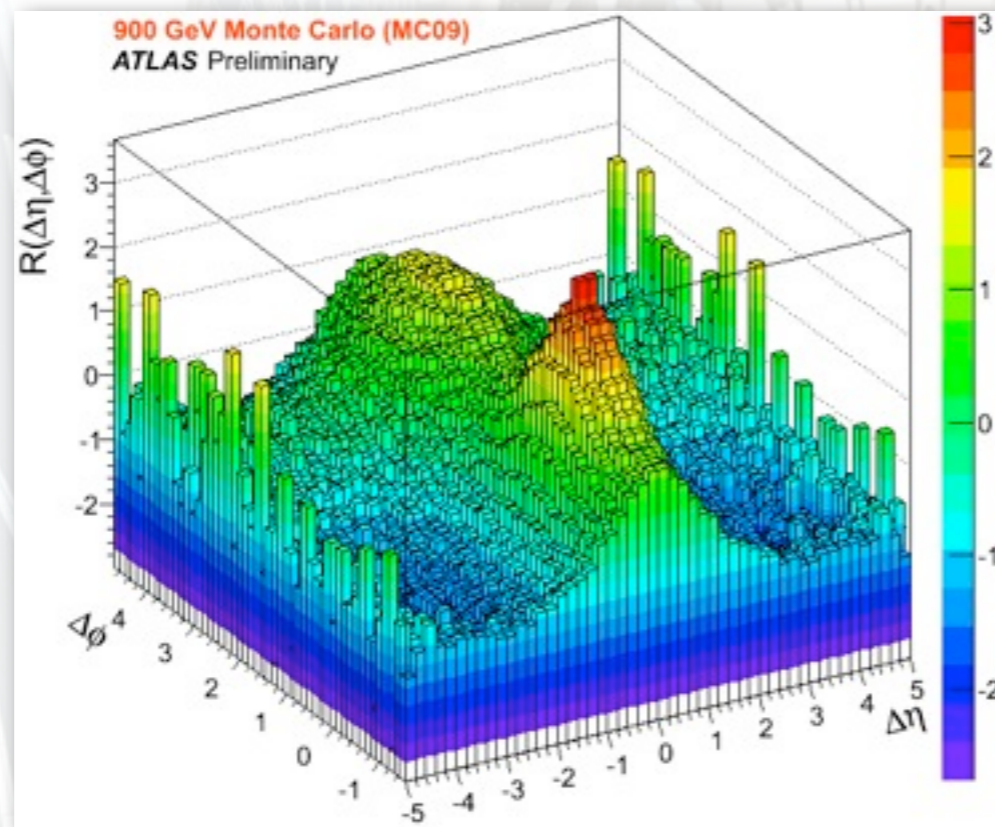
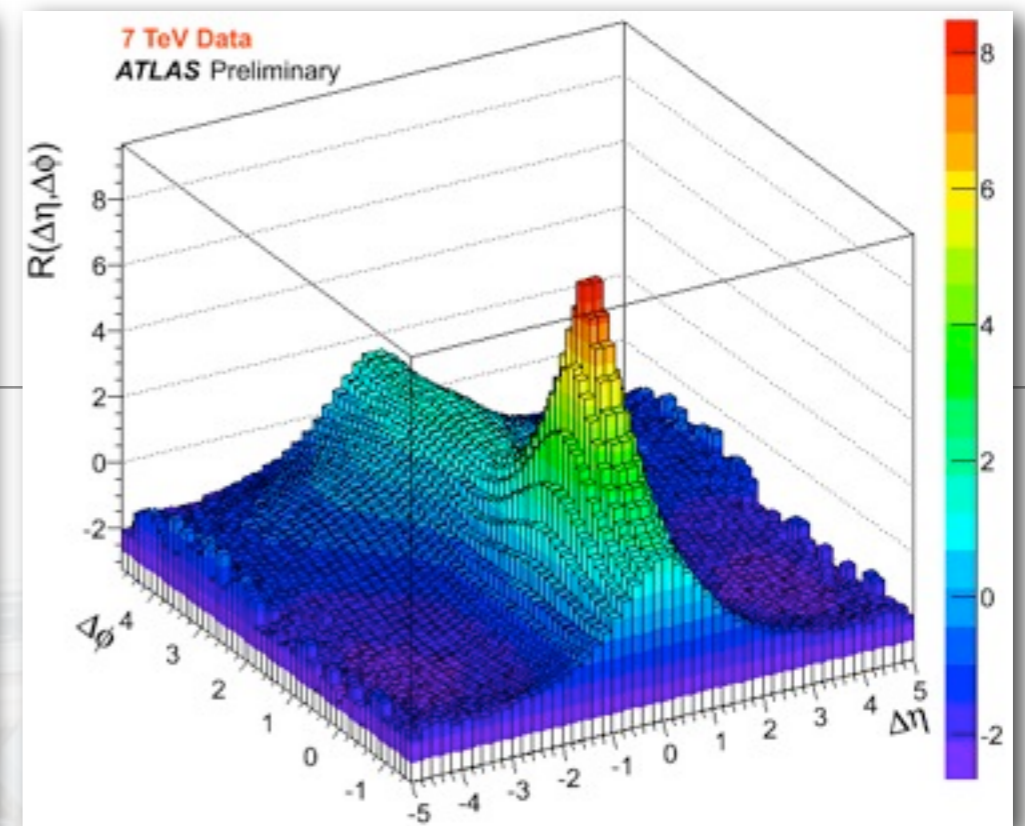
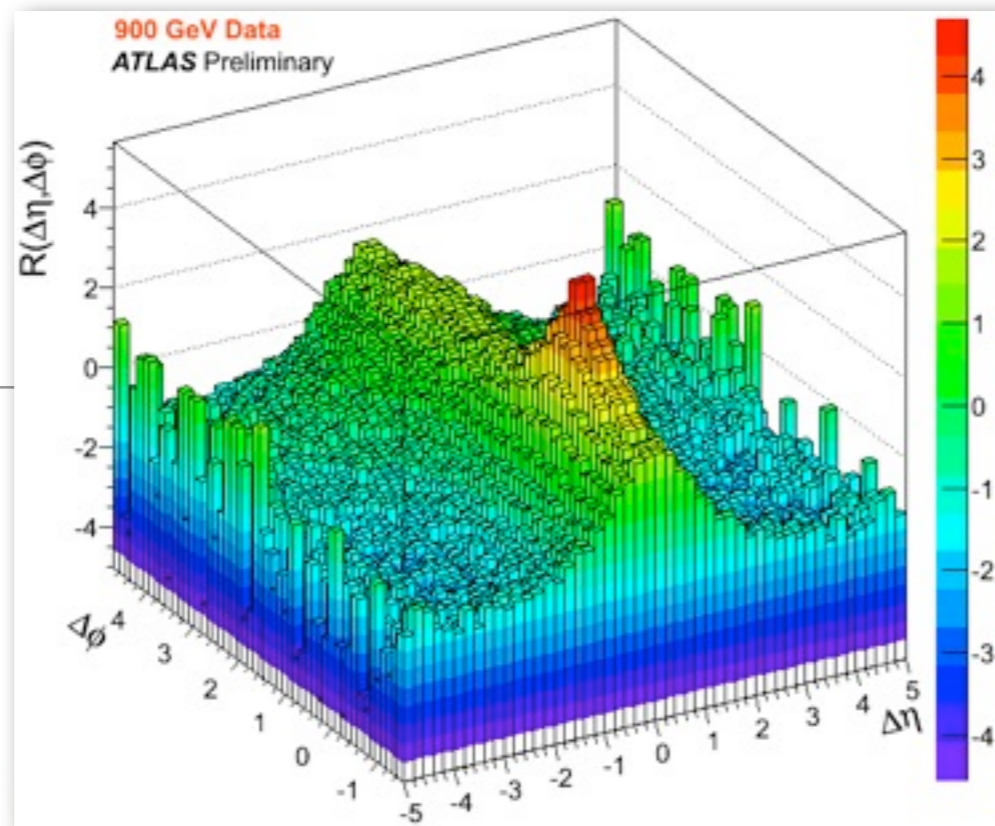
MC studies on the absolute difference between truth and corrected MC as a function of R_{corr} in different models.

An absolute uncertainty of **0.05** is assigned to all bins of R in data.



Results

$$R(\Delta\eta, \Delta\phi)$$

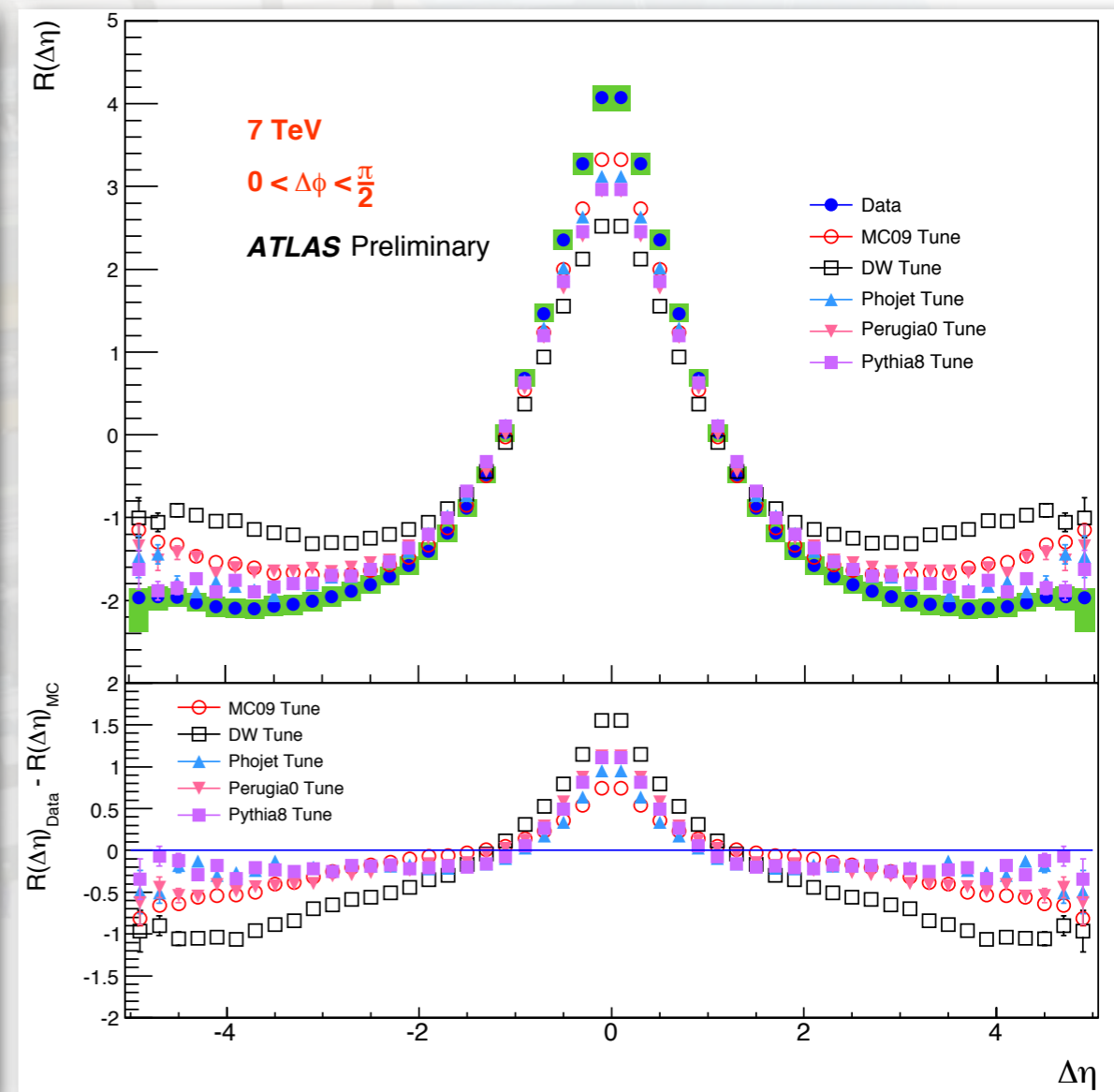
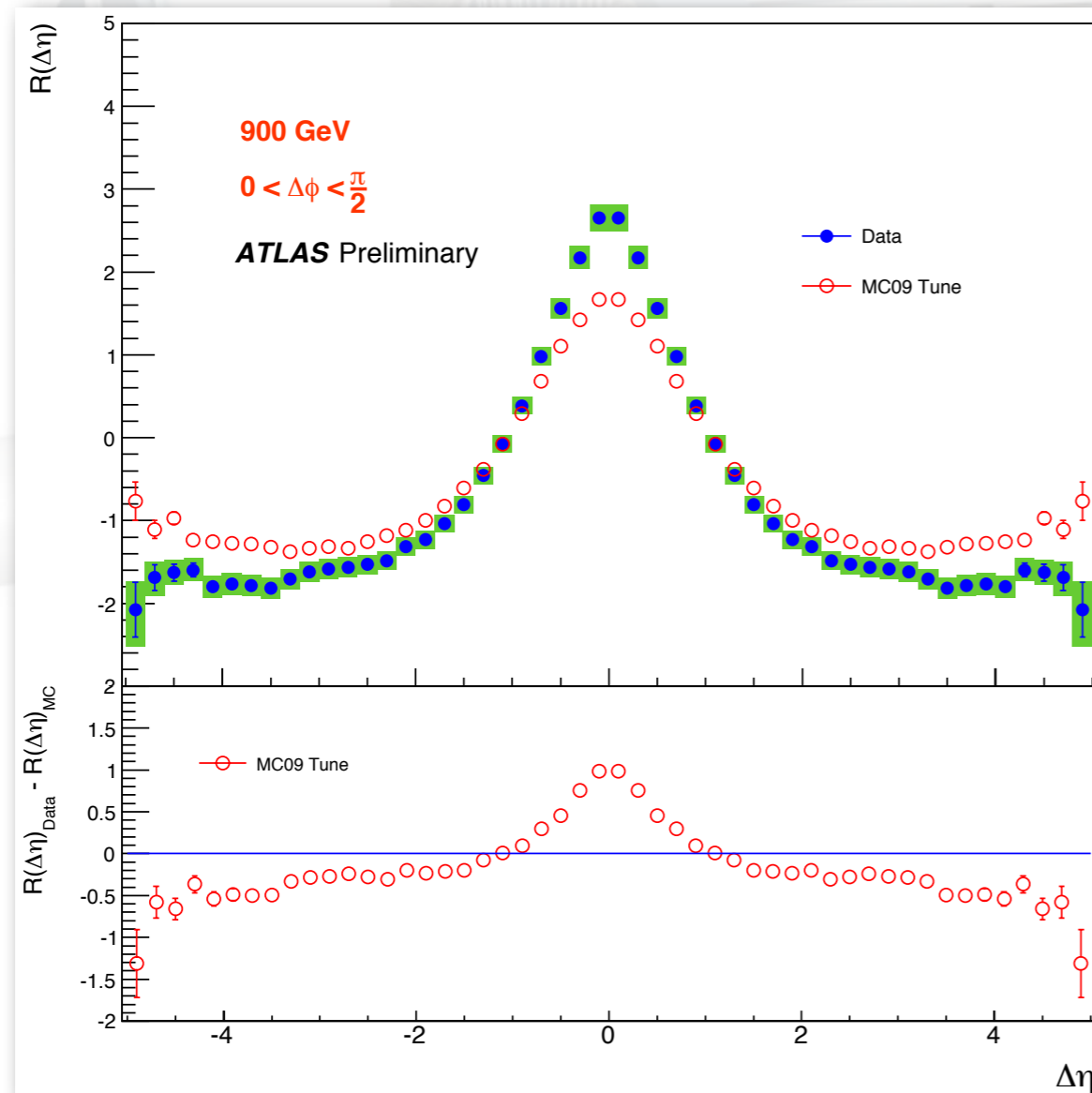


Corrected inclusive two-particle correlation functions in $\Delta\eta$ and $\Delta\phi$. Same complex structure is seen in Monte Carlo, MC09 Tune, however the strength of the correlation seen in data is not reproduced.

Results

Near-side correlations: integrating $0 < \Delta\phi < \pi/2$.

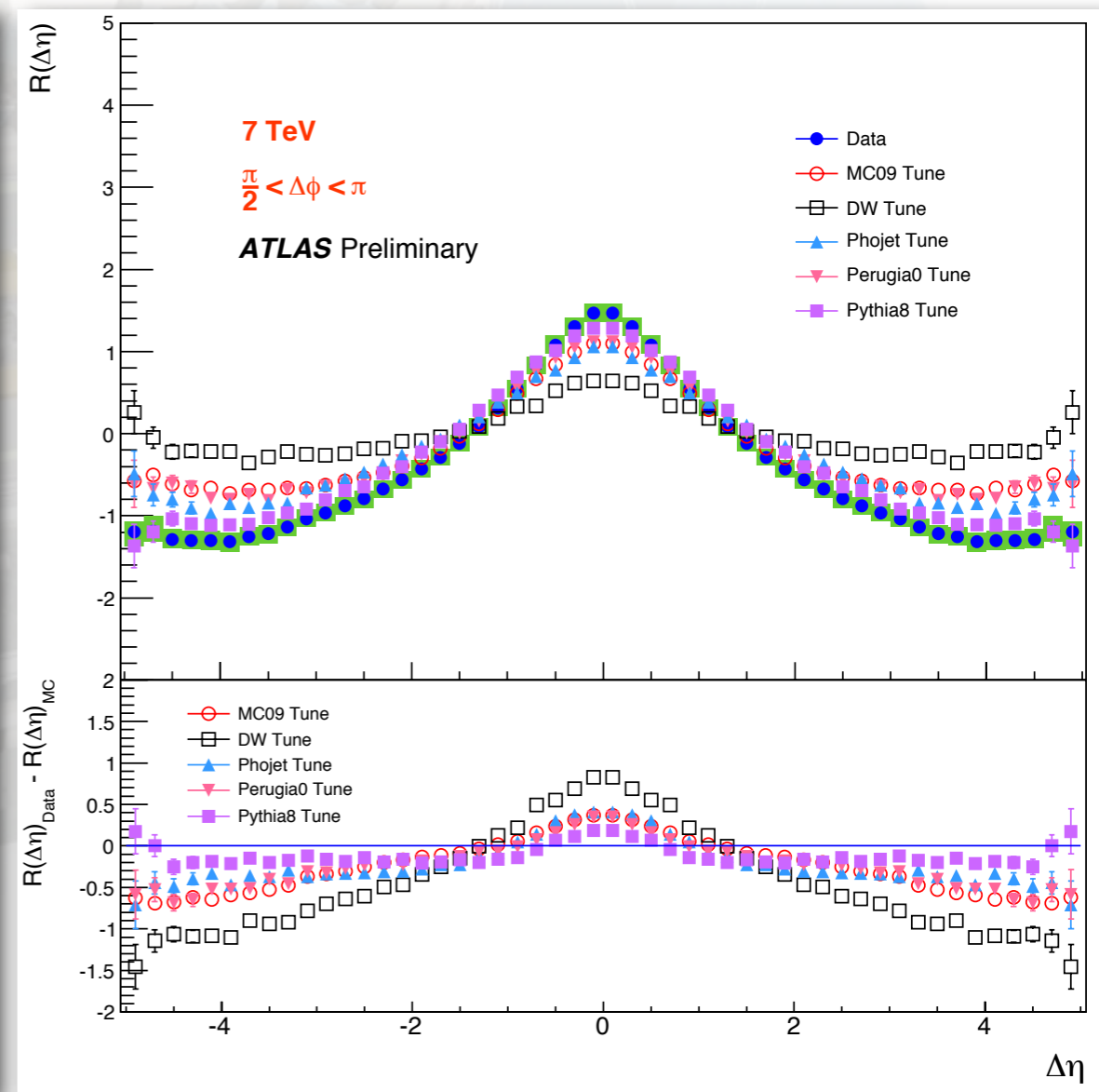
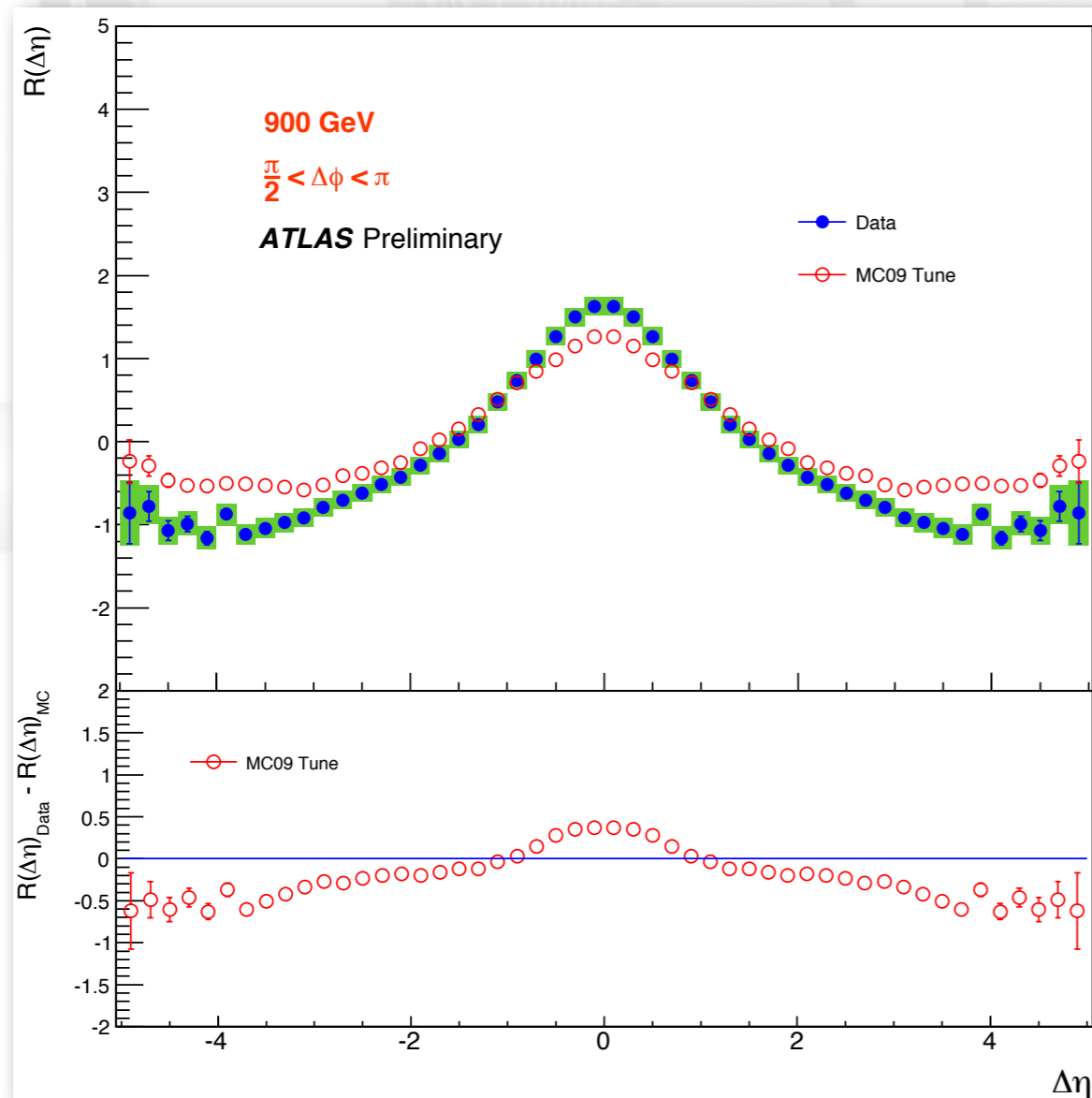
Dominated by the peak at (0,0). At 7 TeV, Pythia 8 and Phojet have better agreement in the tails of the distribution while MC09 is closer in the peak.



Results

Away-side correlations: integrating $\pi/2 < \Delta\phi < \pi$.

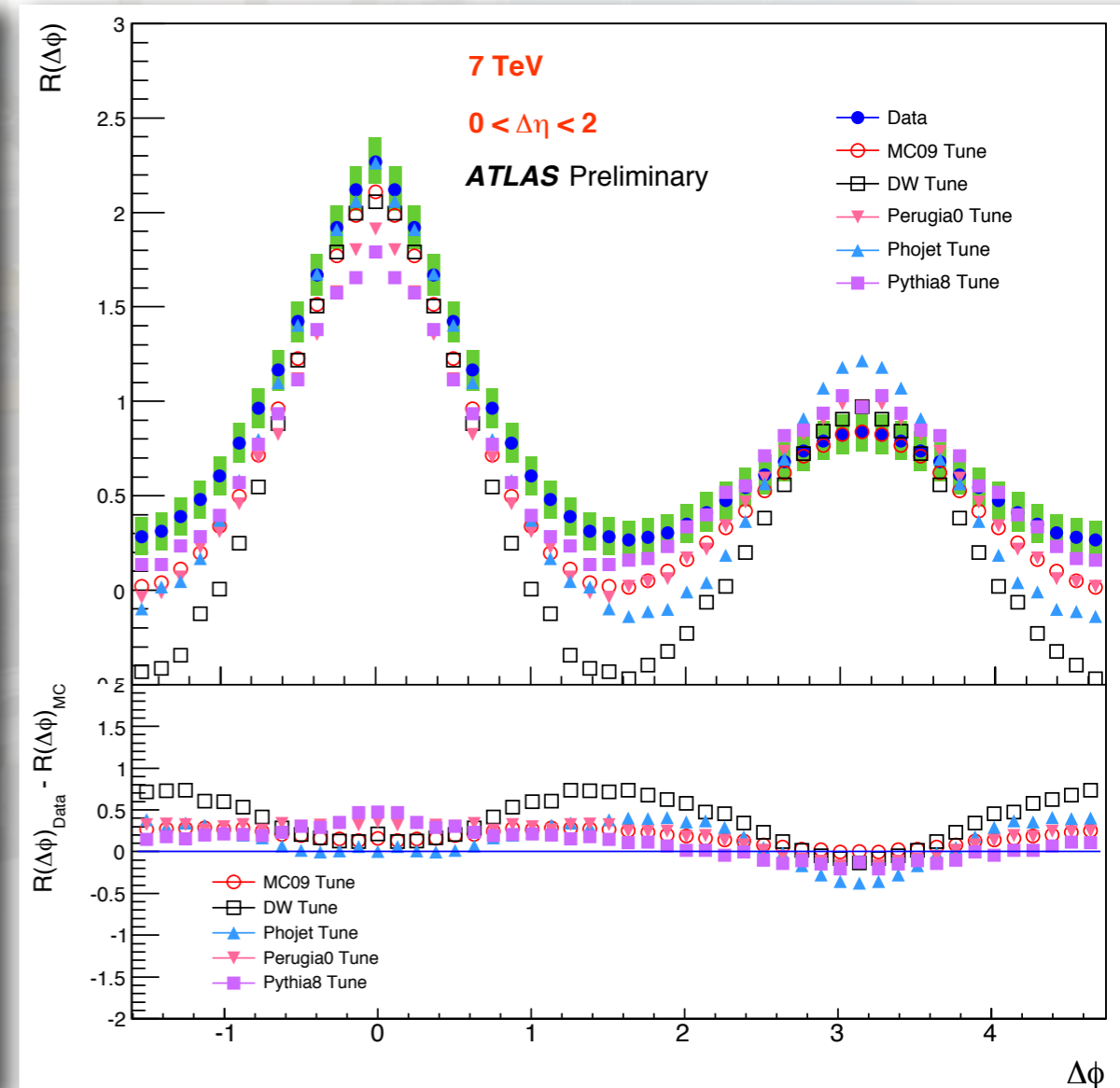
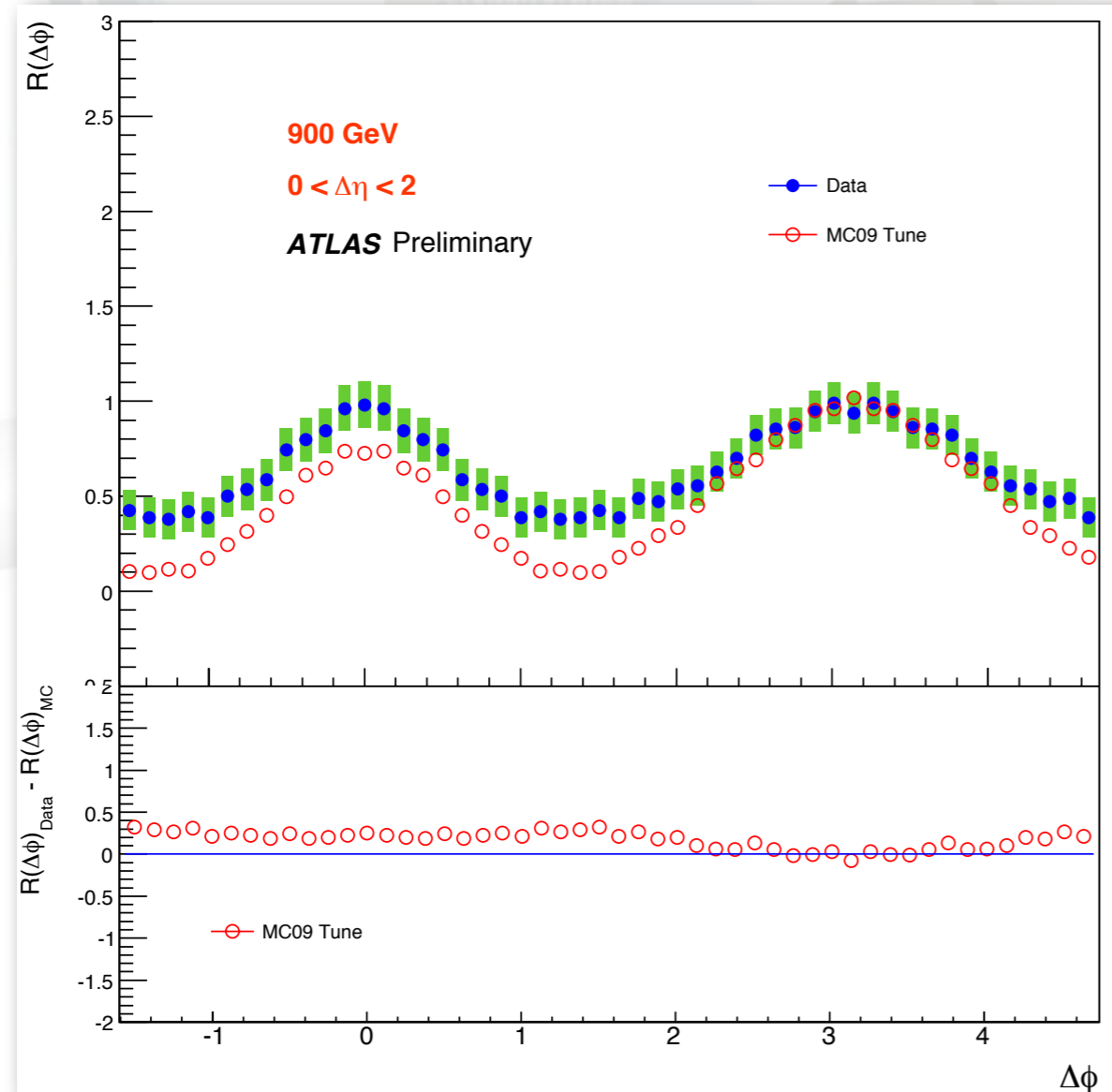
Dominated by the ridge structure around $\Delta\phi=\pi$. With the exception of DW, the tunes seem to perform better in these distributions.



Results

Short-range correlations: integrating $0 < \Delta\eta < 2$.

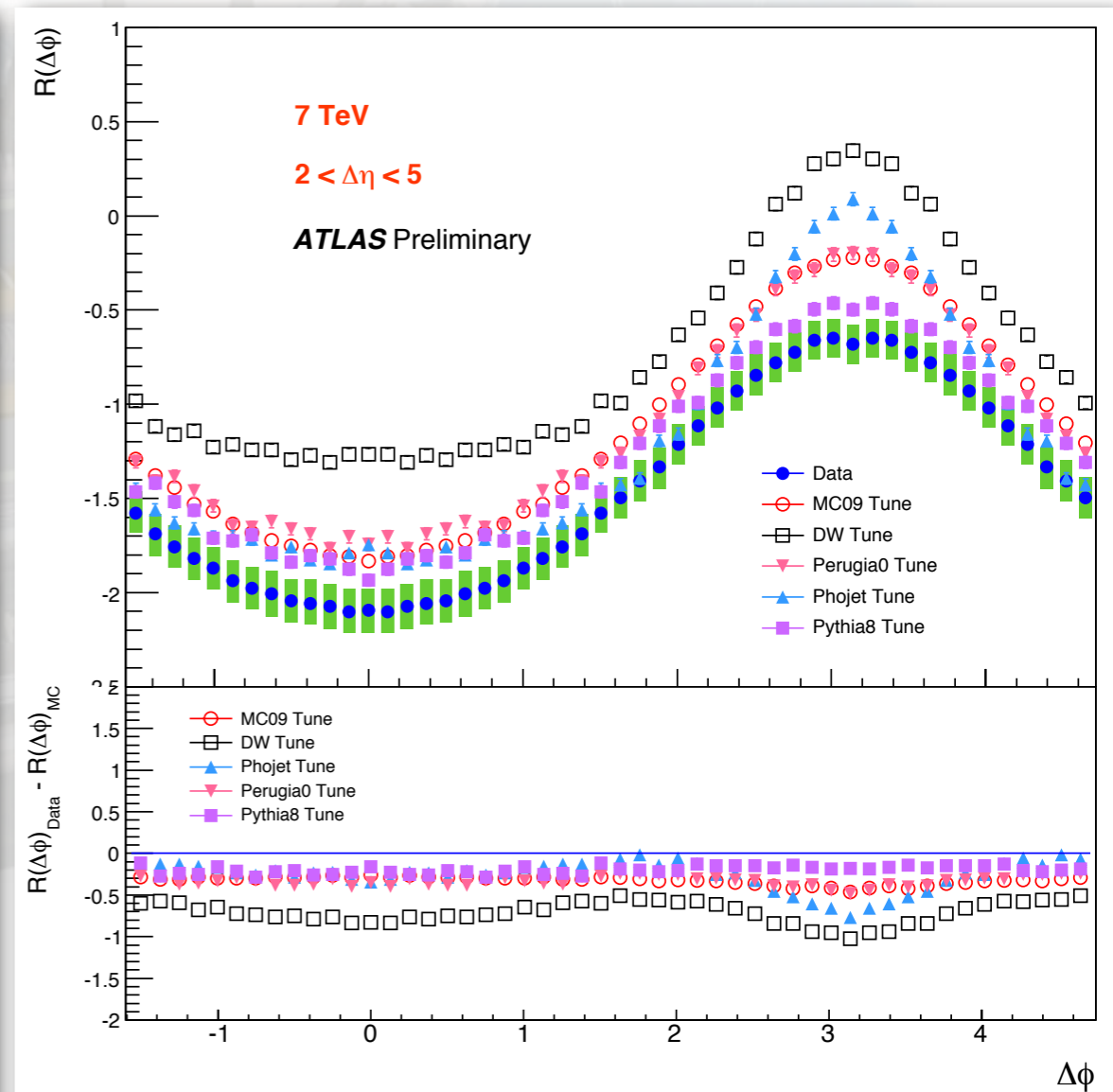
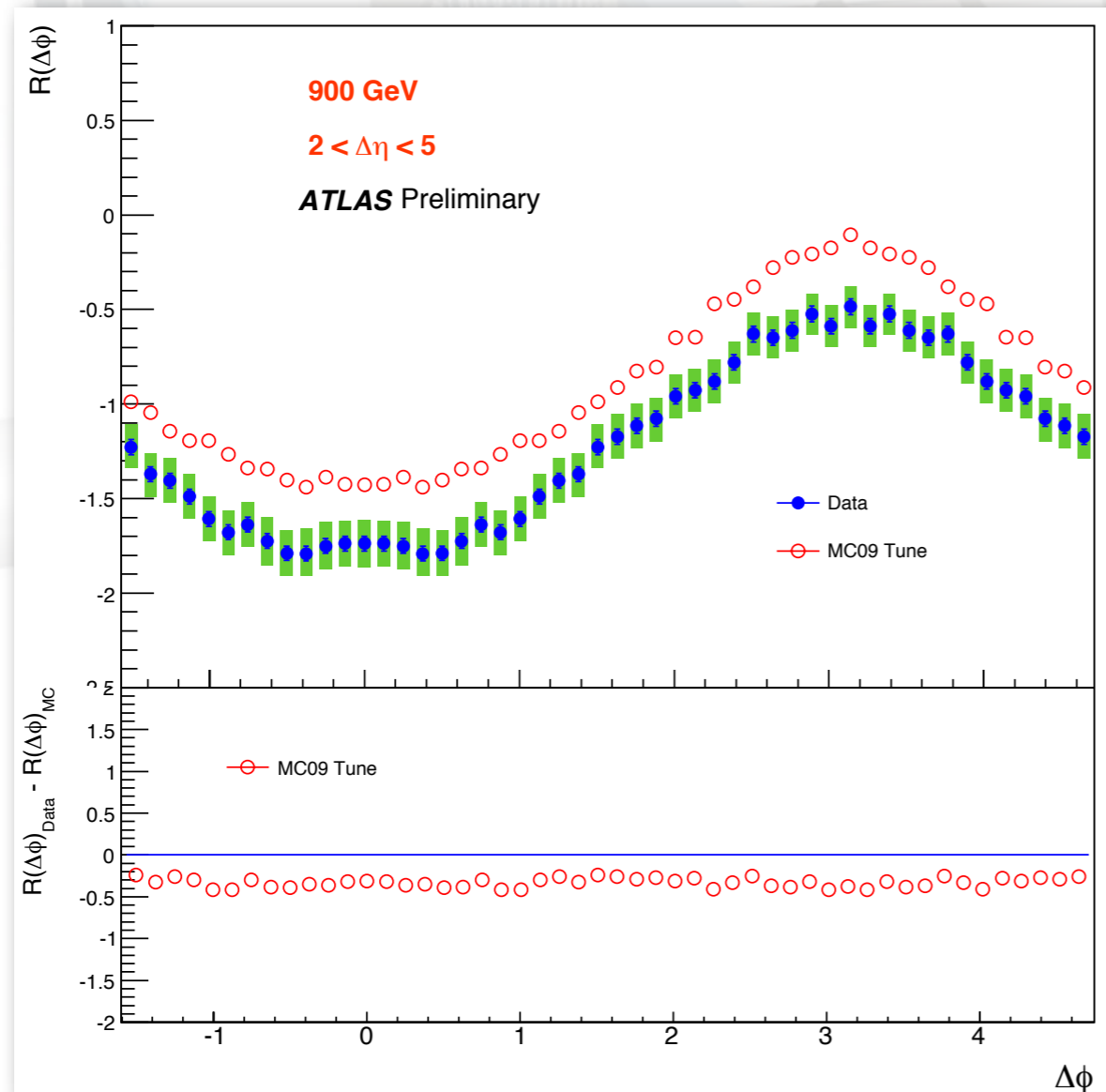
Two-peak structure. Similar to underlying event distributions. Back-to-back recoil. Most of the tunes agree well with data in a small region around $\Delta\phi = \pi$.



Results

Long-range correlations: integrating $2 < \Delta\eta < 5$.

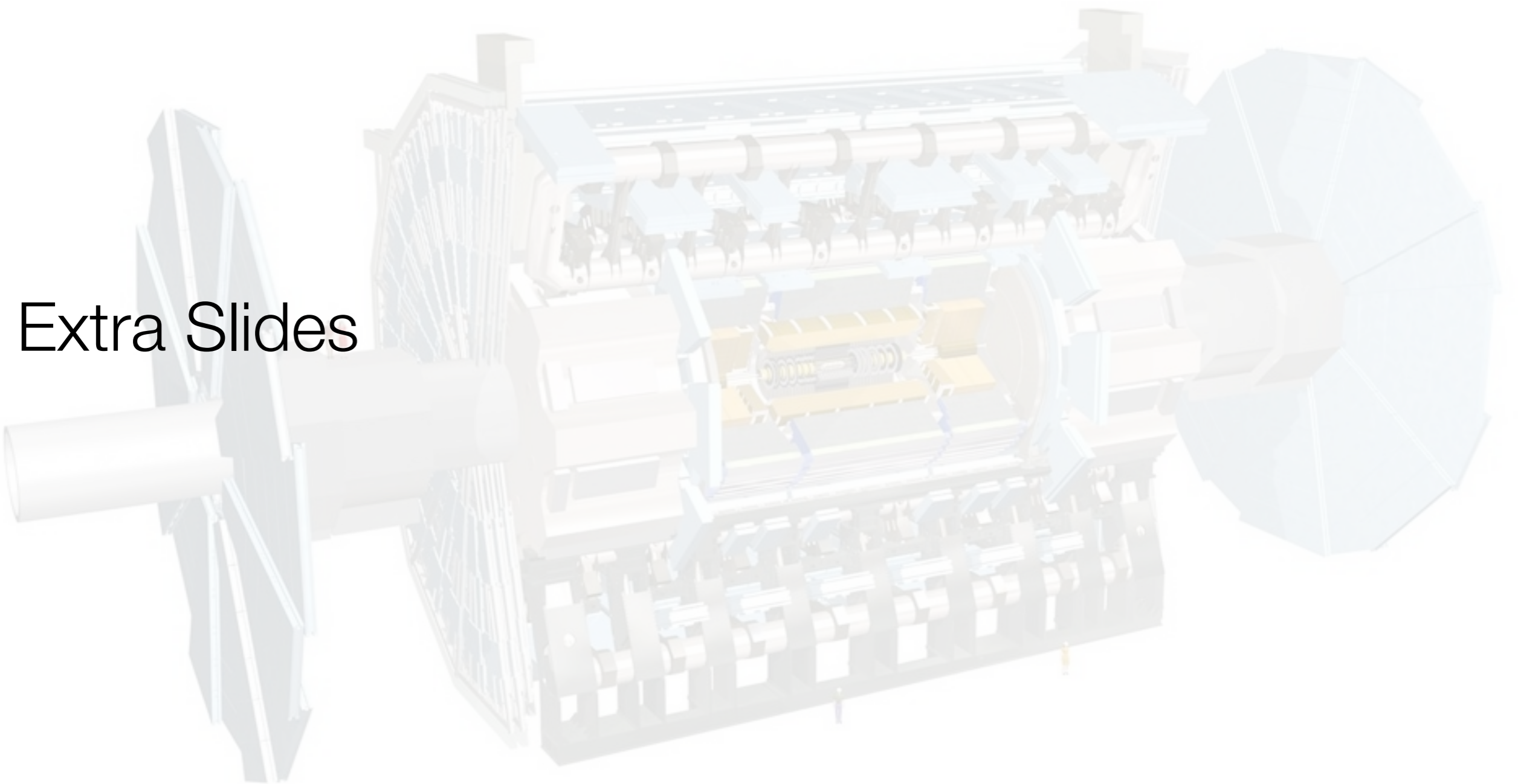
Underlying structure away from the peak at (0,0). The absolute difference between data and the different models is flat across $\Delta\phi$. Pythia 8 is closest and DW (old tune) is worst.



Summary

- The two-particle angular correlation function in $\Delta\eta$ and $\Delta\phi$ has been measured for p_T inclusive minimum bias events in pp collisions at 900 GeV and 7 TeV.
- A complex structure was observed at both energies. It was explored in more detail by projecting the two-dimensional distribution into both $\Delta\eta$ and $\Delta\phi$.
- The results have been compared to different Monte Carlo tunes: MC09, Phojet, DW, Perugia₀ and Pythia 8 (further information on these tunes in Extra Slides).
- None of the models reproduce the strength of the correlations seen in data. The Pythia 8 tune at 7 TeV is the closest in all distributions.

Exciting times! Many more measurements to come!

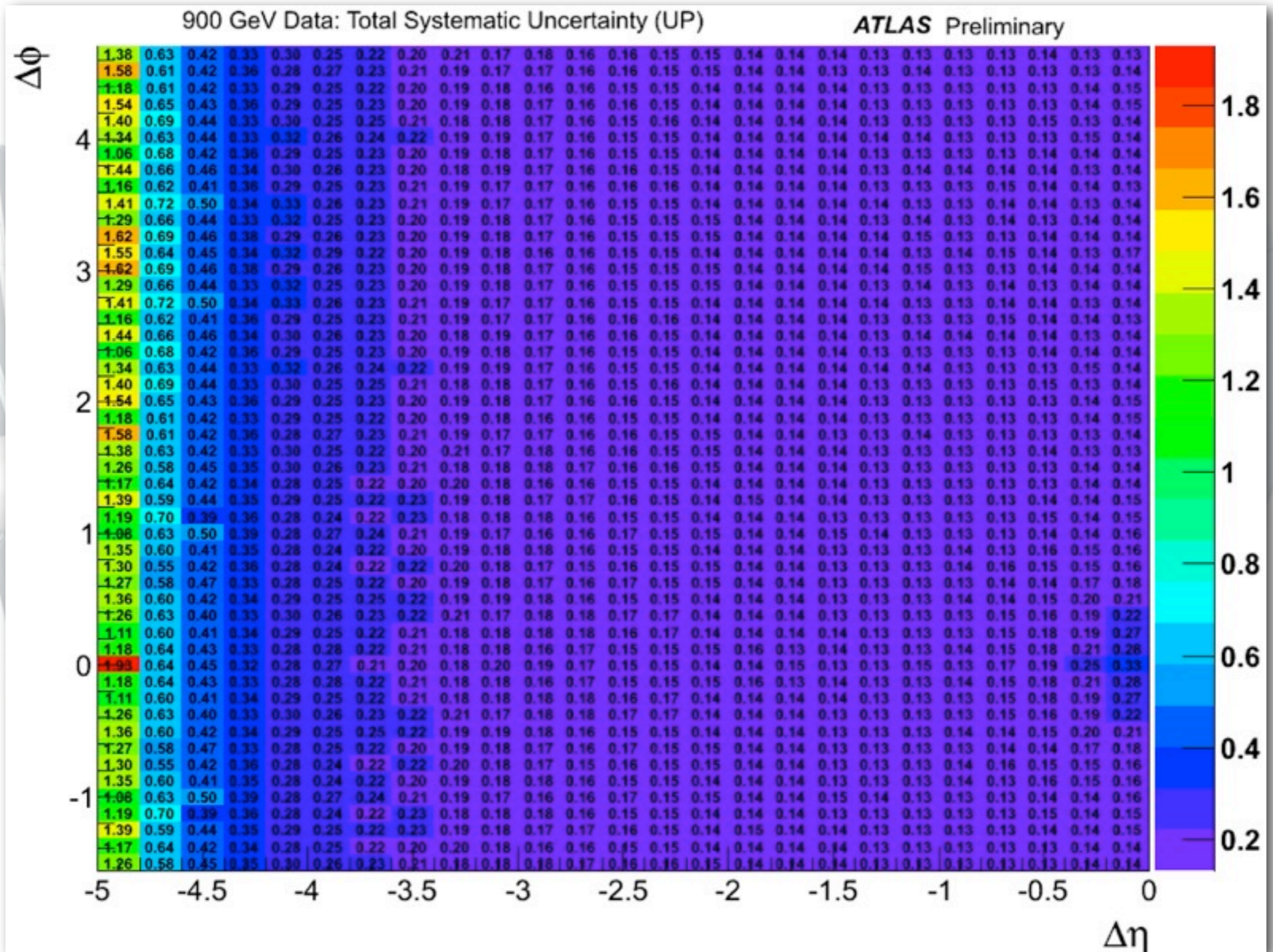


Extra Slides

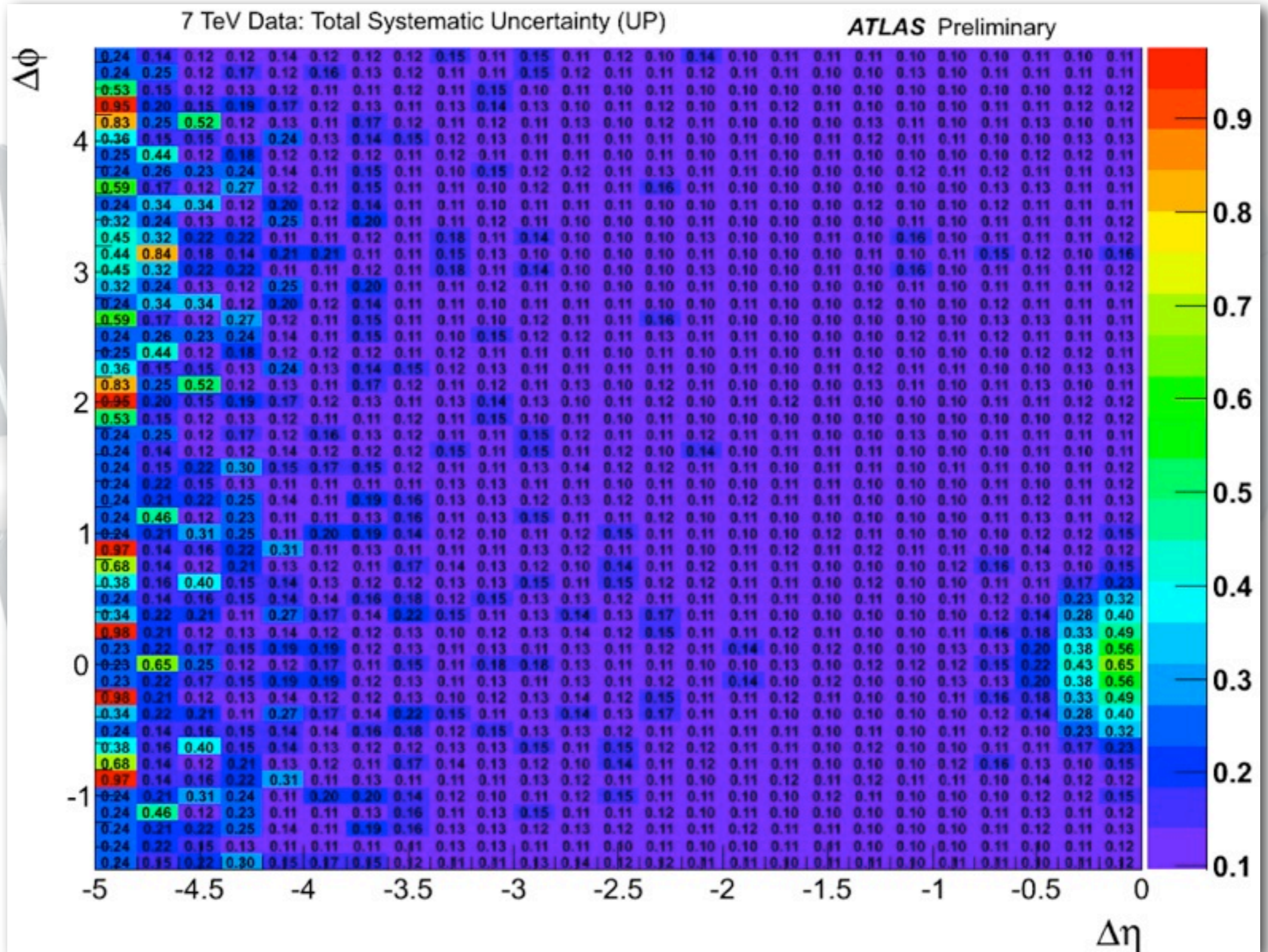
Monte Carlo Models - 2PC analysis

- Pythia 6.4.21 tunes:
 - **MC09**: produced by the ATLAS Collaboration to describe a range of minimum bias and underlying event data from the Tevatron; uses MRST LO* PDF.
 - **DW**: older tune to CDF underlying event and Drell-Yan data; uses the older virtuality-ordered shower and non-interleaved MPI model.
 - **Perugia₀**: tuned to Tevatron; uses CTEQ 5L PDF and the new p_T ordered shower and the MPI is interleaved with the initial state radiation.
- **Phojet 1.12.1.35**: separate hard and soft diffractive contributions; not yet tuned to recent experimental data.
- **Pythia 8.130**: adds to the MPI model of Pythia 6 by also interleaving the final state radiation; includes an updated model for diffraction that allows harder colour singlet exchange; uses CTEQ 5L PDF.

Total Uncertainties for 2D distributions - 2PC



Total Uncertainties for 2D distributions - 2PC



7 TeV

$\Delta\phi$ Correlations



ATLAS Note:

“Angular correlations between charged particles from proton-proton collisions at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV measured with ATLAS detector”

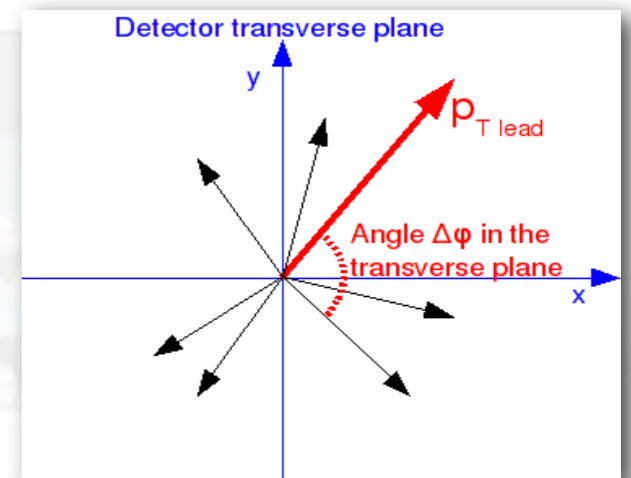
<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-082/>

Analysis Overview

Some definitions:

leading particle - charged particle with highest transverse momentum (p_T).

$\Delta\phi$ - azimuthal angle difference. Unsigned angle in the transverse plane (x-y) between the leading particle and any non-leading particle.

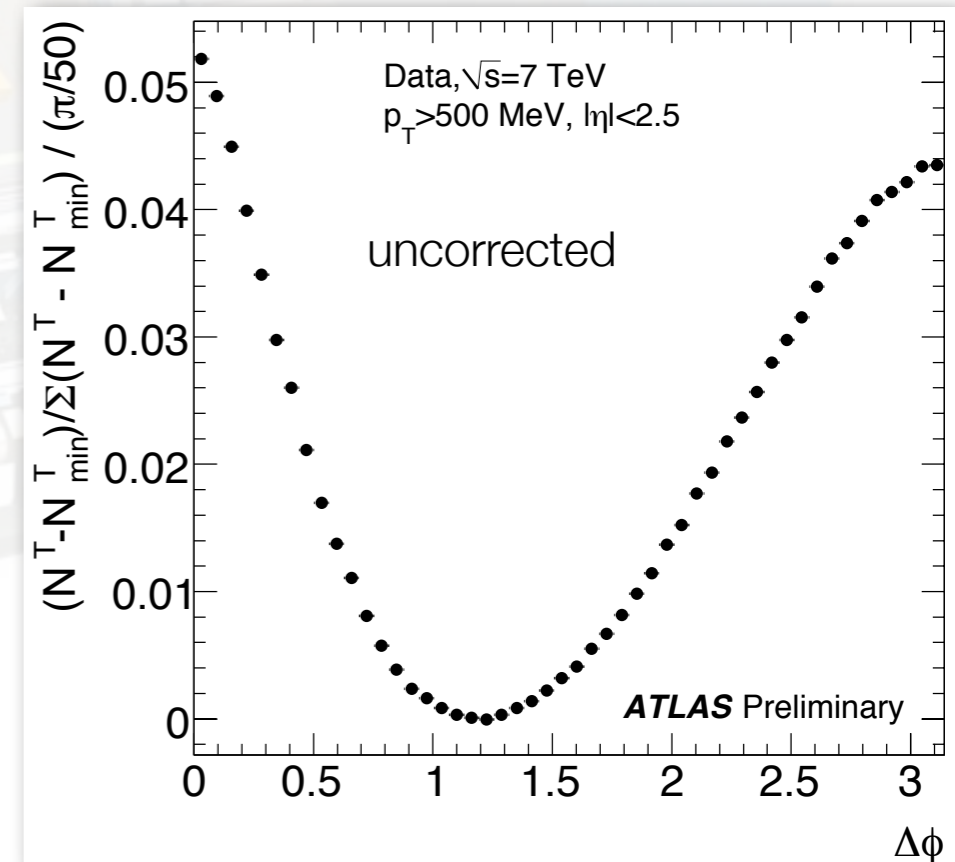
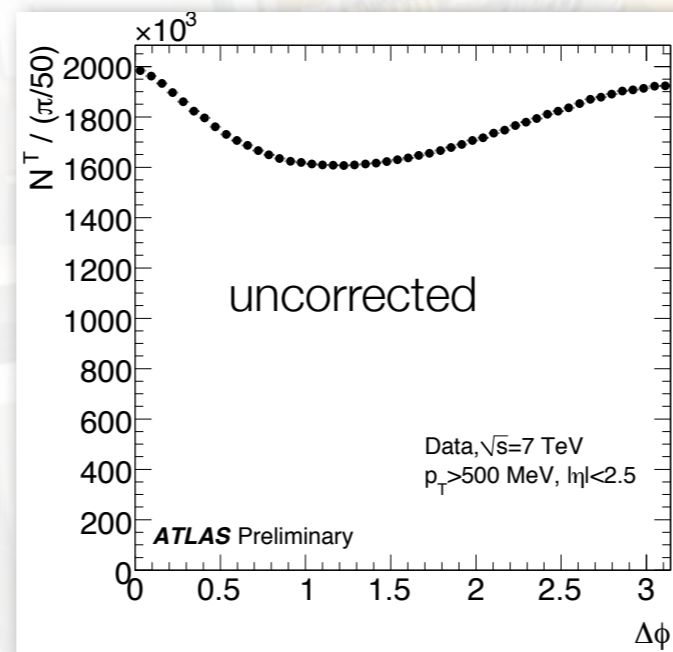


$\Delta\phi$ crest shape observable

$\Delta\phi$ for all non-leading particles in an event.

The minimum of the distribution is extracted from a 2nd degree-polynomial fit.

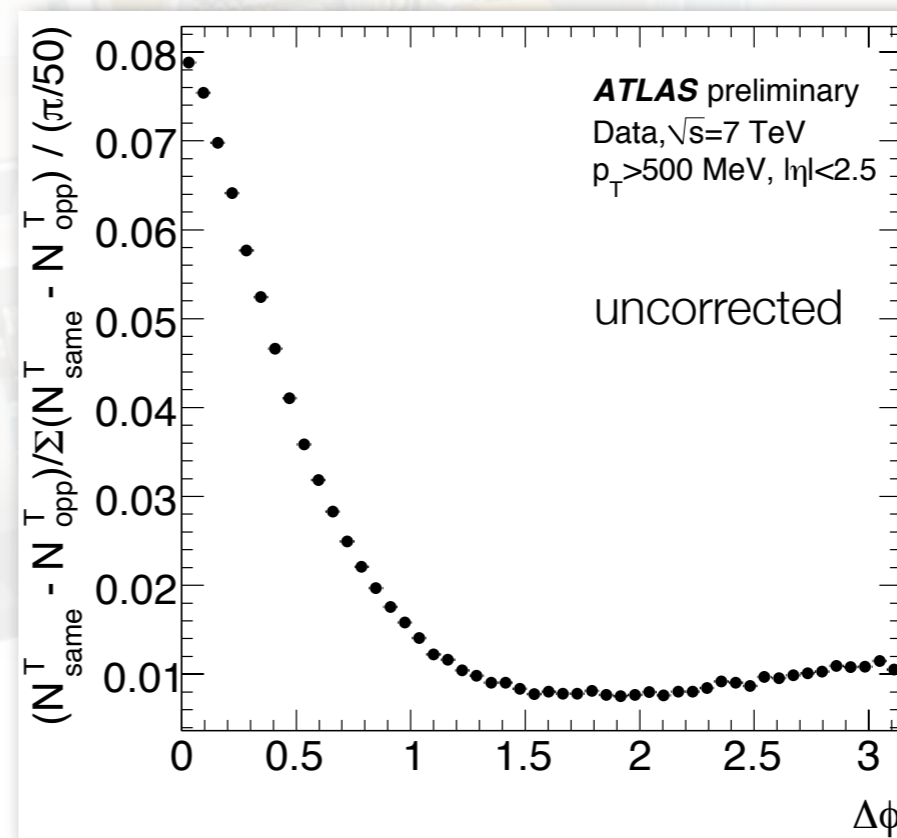
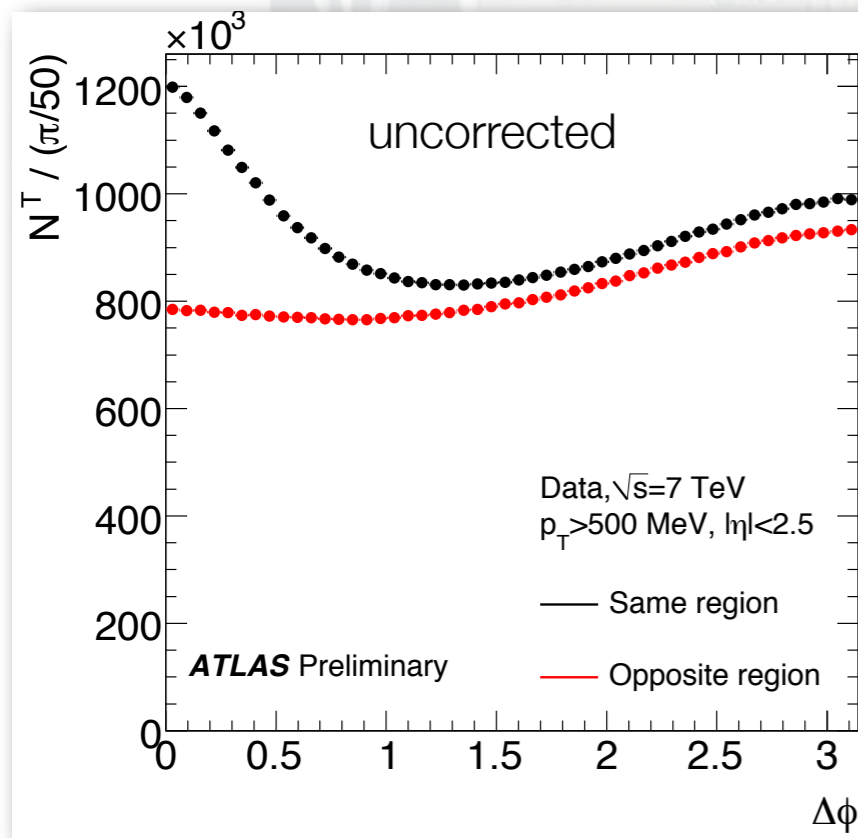
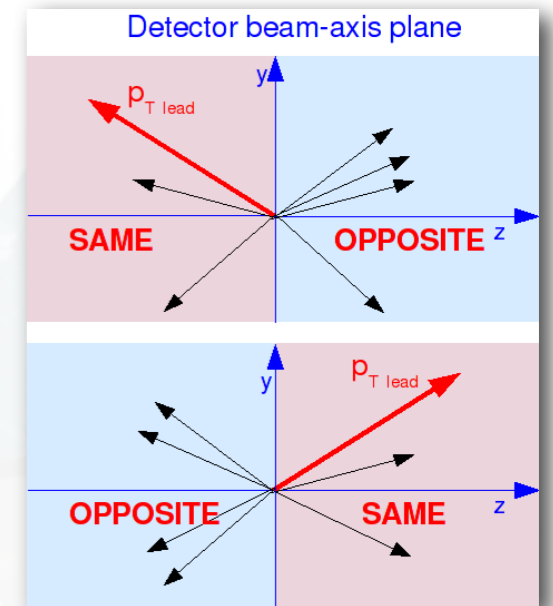
Subtract the minimum from each bin and normalise to unit area.



Analysis Overview

$\Delta\phi$ “same minus opposite” observable

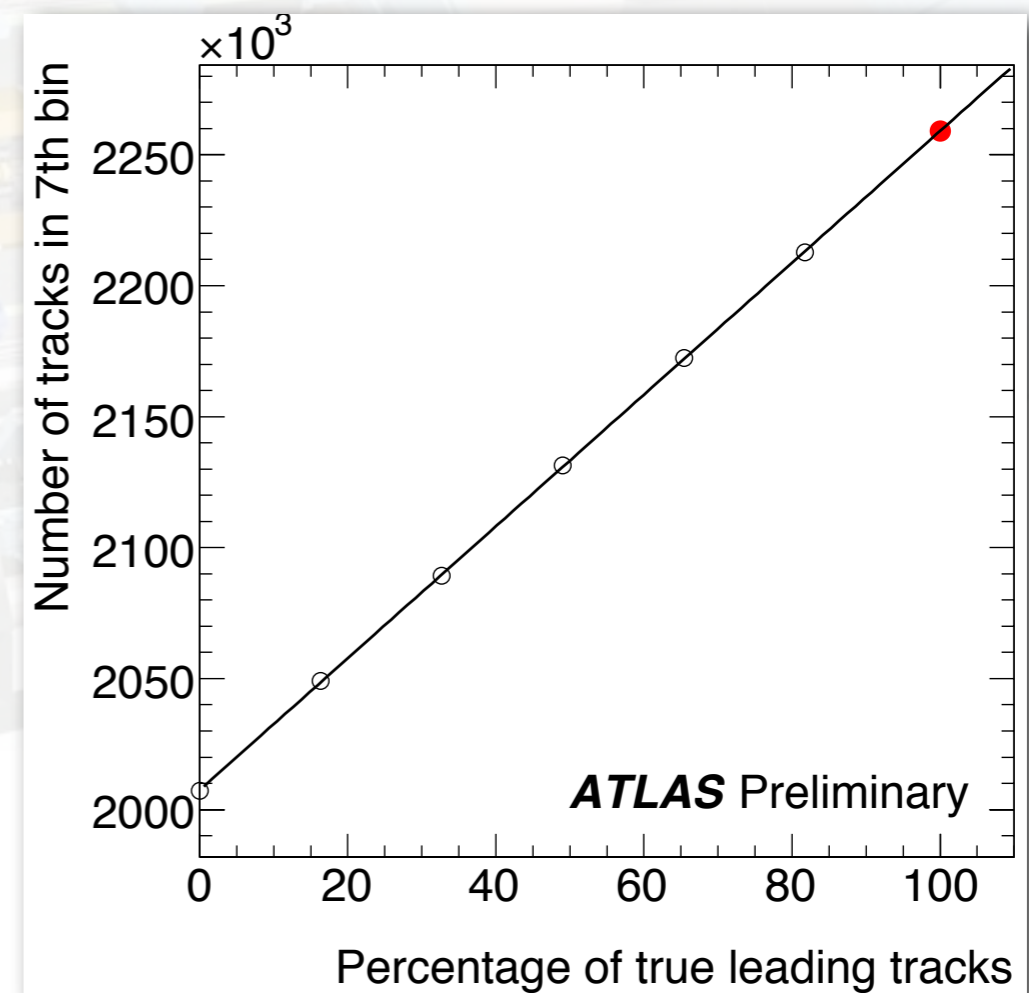
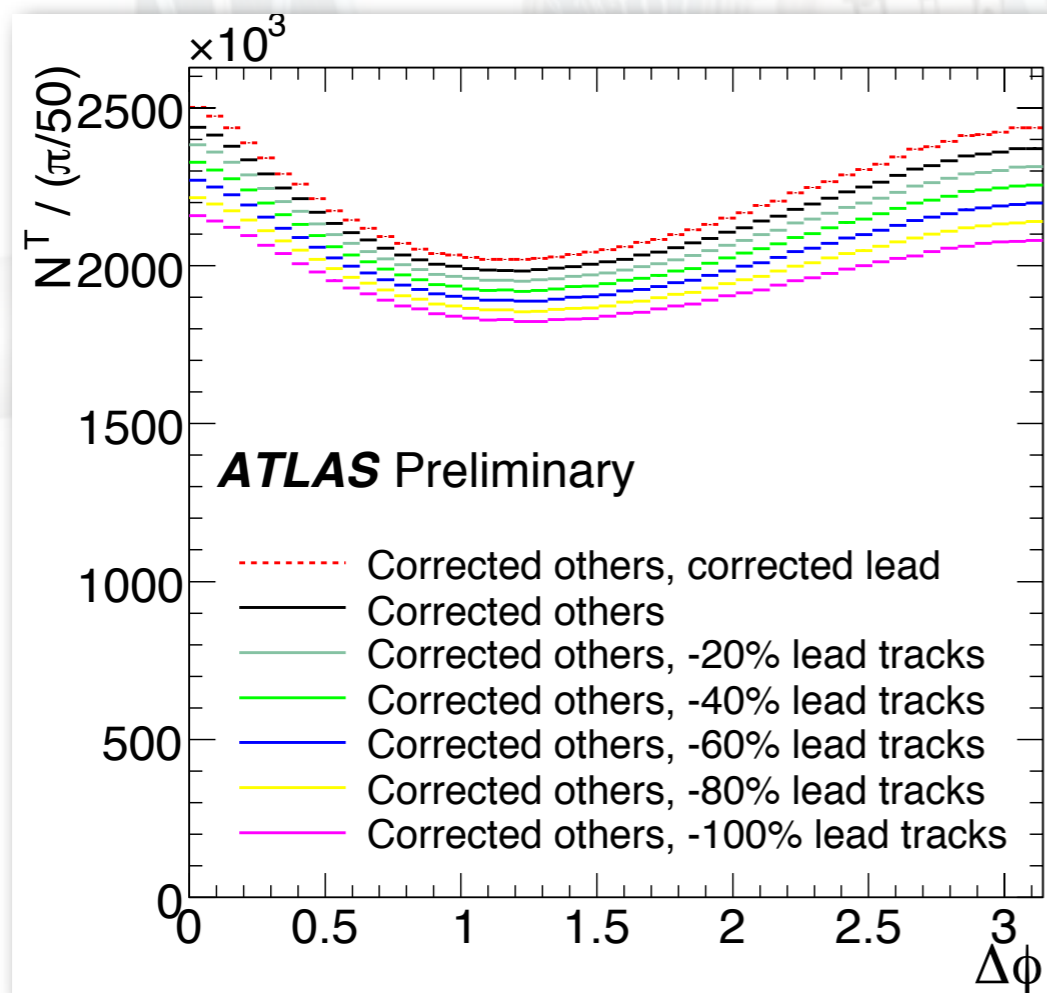
- Divide each event into two η regions according to the η of the leading particle.
- Plot $\Delta\phi$ for particles with η of the same/opposite sign as the leading particle.
- Subtract the “opposite region” from the “same region” and normalise.



Correction Procedure

Tracking Efficiency in p_T and η

- Loss of non-leading tracks: corrected for using a weight per entry.
- Loss of leading tracks: bin-by-bin shape correction based on how the shape of the distribution changes when more leading tracks are removed.



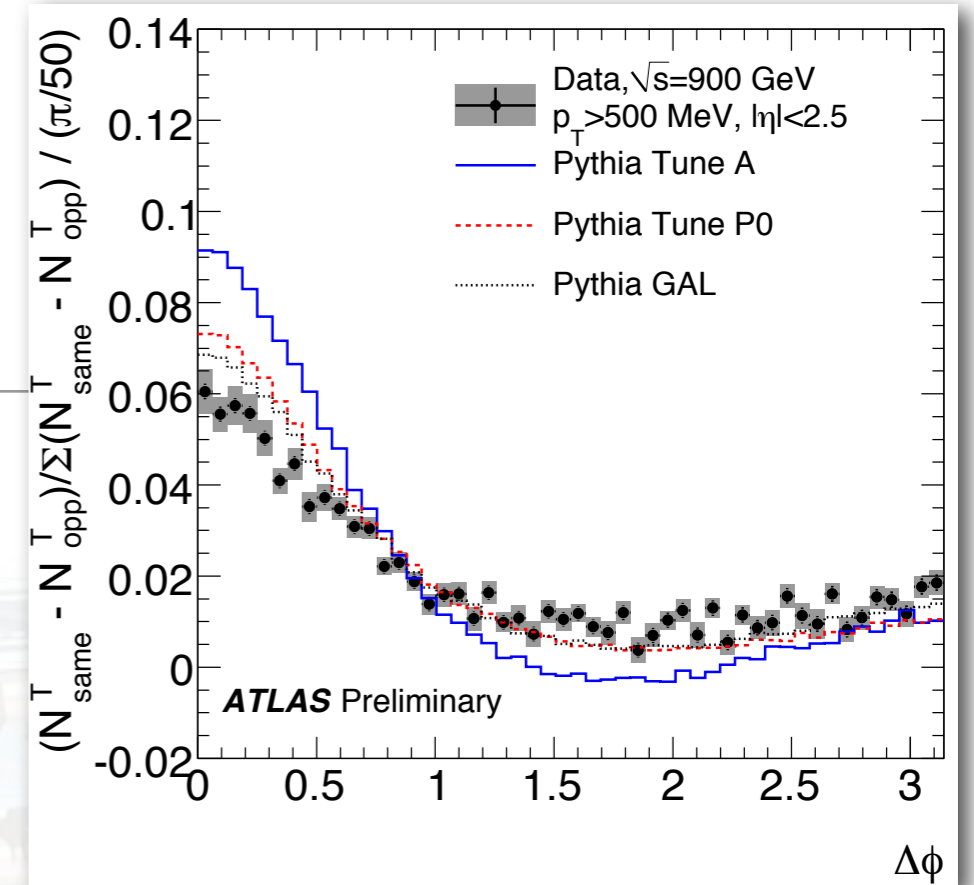
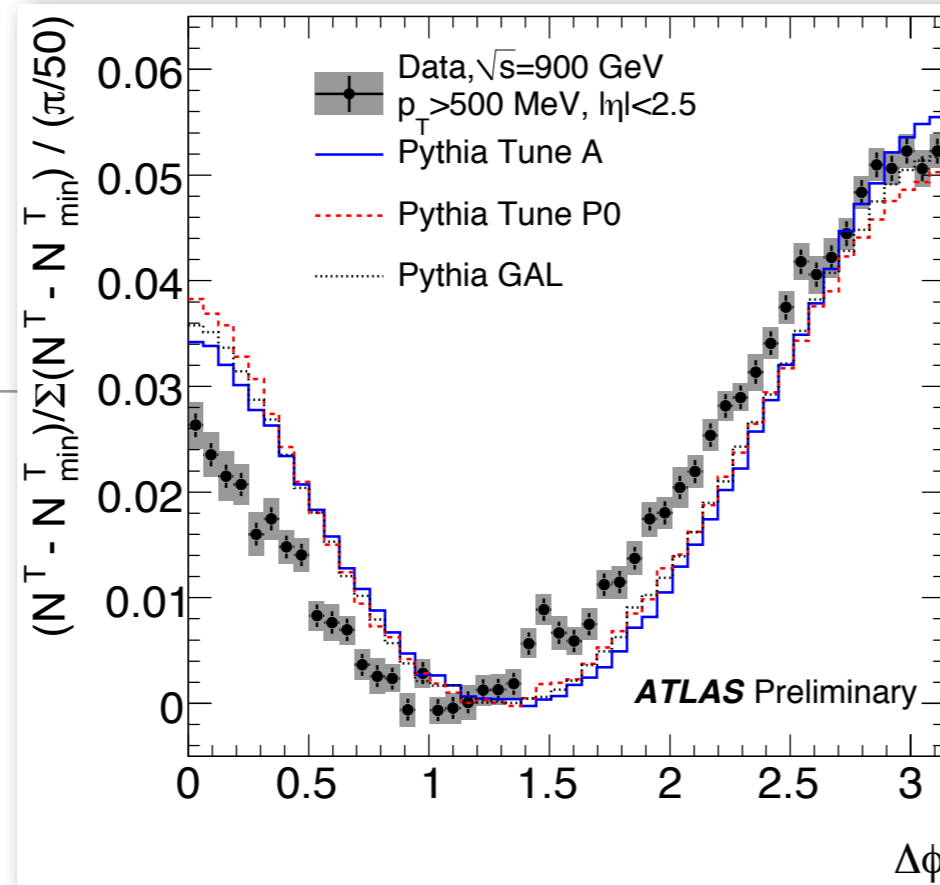
Statistical and Systematic Uncertainties

Summary of systematic uncertainties. The total uncertainty is obtained by adding in quadrature all of the contributions and the statistical uncertainty.

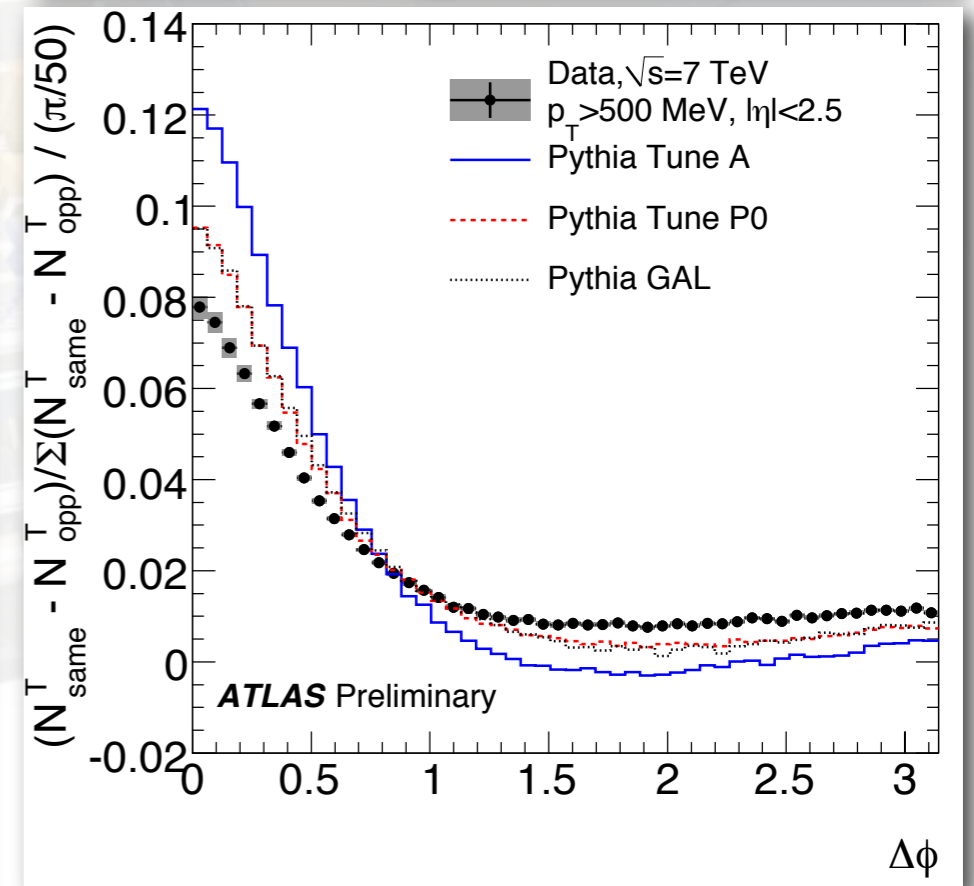
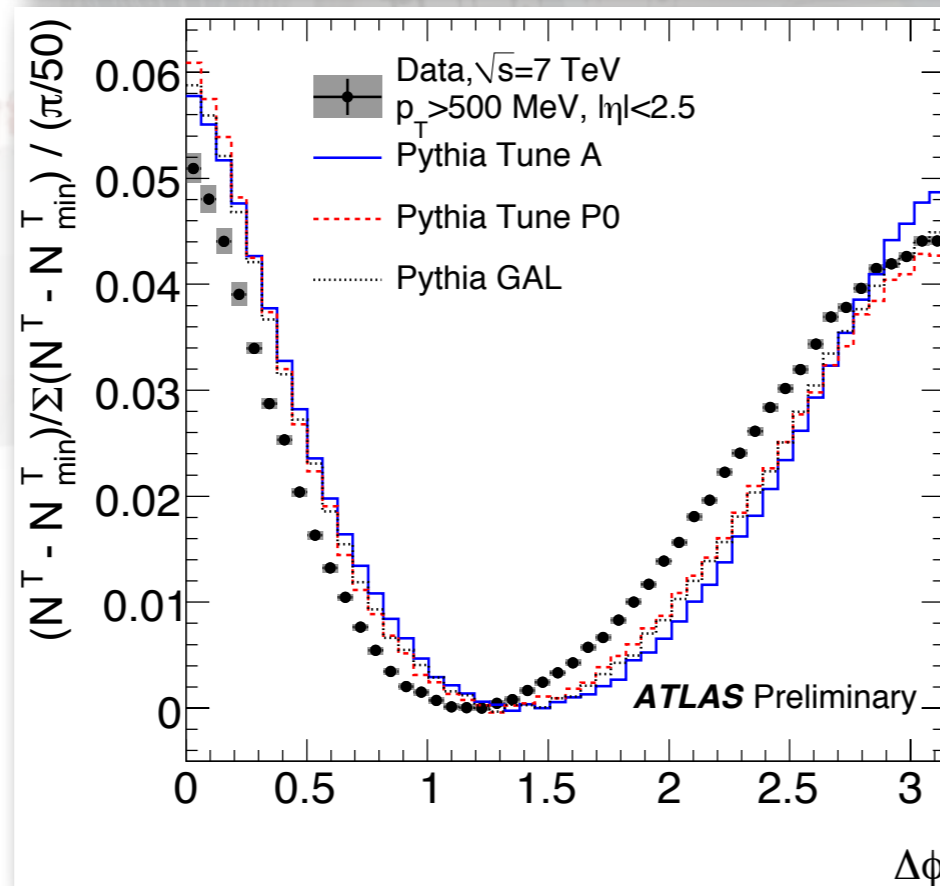
Table 1: Systematic uncertainties, summary table

Source of systematic uncertainty	Implemented	Relative uncertainty in first bins
Event selection inefficiency	bin-by-bin	1%-3%
Bias remaining after corrections	2% in first 4 bins	2%
Resolution - phase space boundaries	bin-by-bin	1%-2%
Resolution - leading track	bin-by-bin	0.1%-0.2%
Efficiency of leading tracks	bin-by-bin	0.1%-0.2%
Efficiency of non-leading tracks	0.2% in each bin	0.2%
ϕ dependence of the tracking efficiency	6×10^{-5} in each bin	0.1%-0.2%
Choice of the d_0^{PV} cut	9×10^{-5} in each bin	0.1%-0.3%
Statistical uncertainty		900 GeV: 3%-4% 7 TeV: 0.3%-0.4%

Results

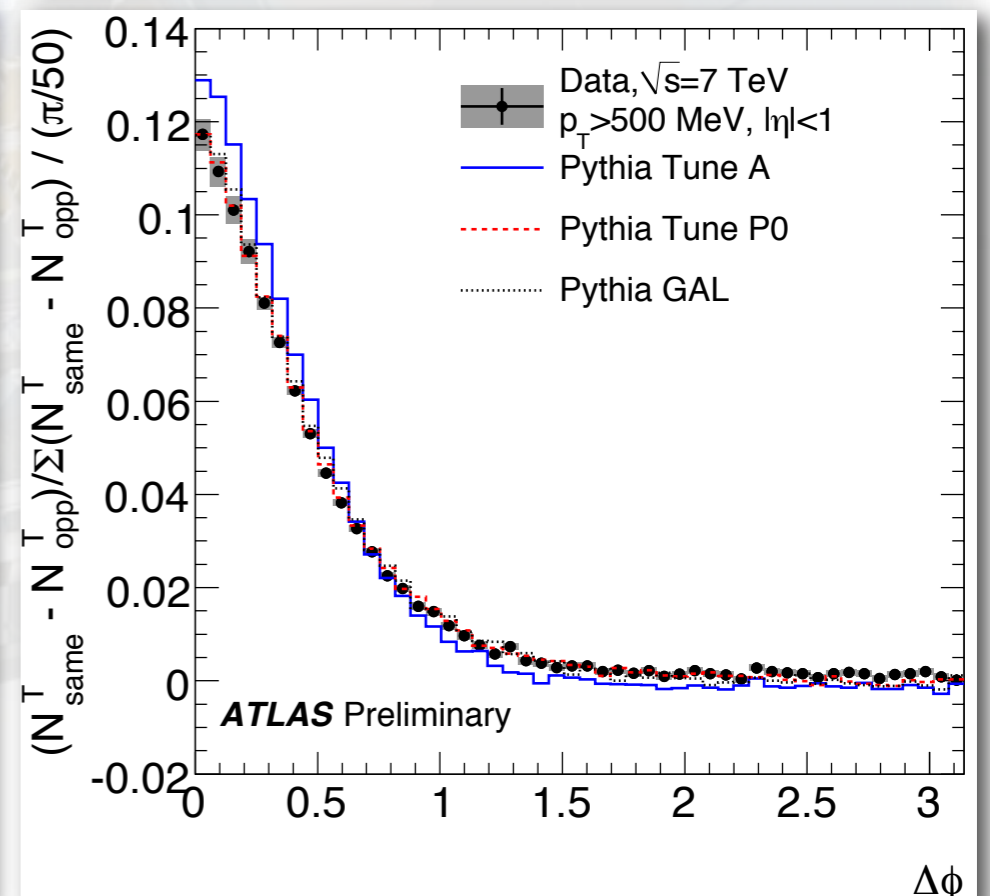
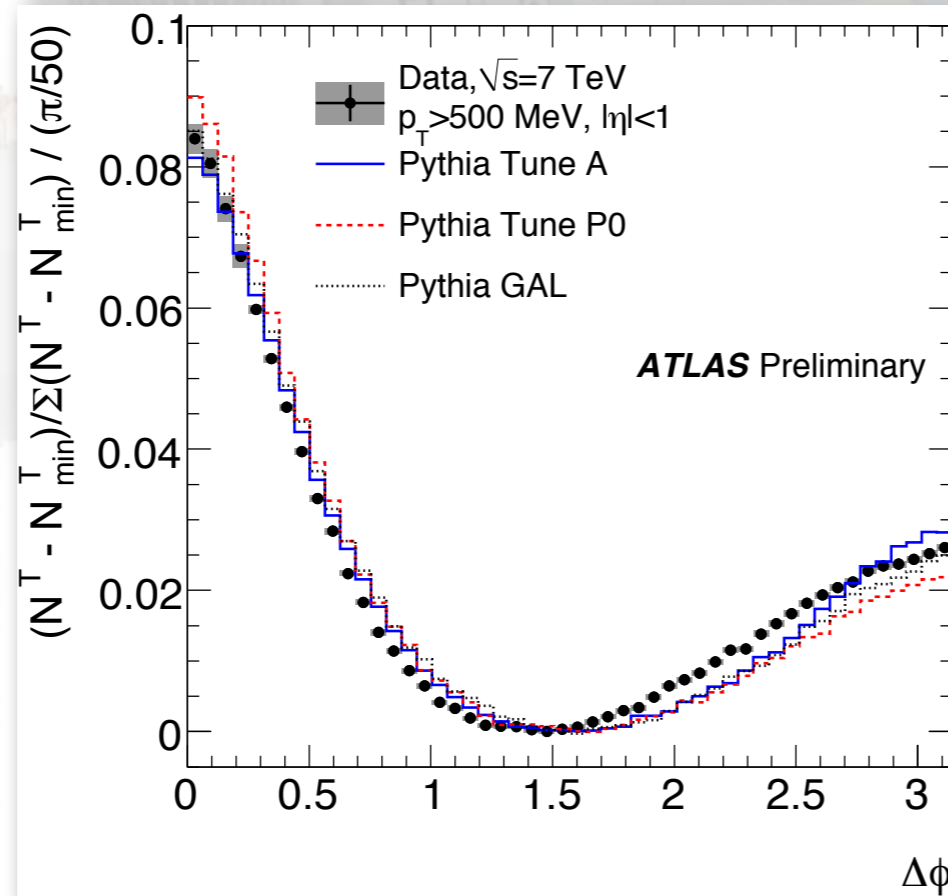
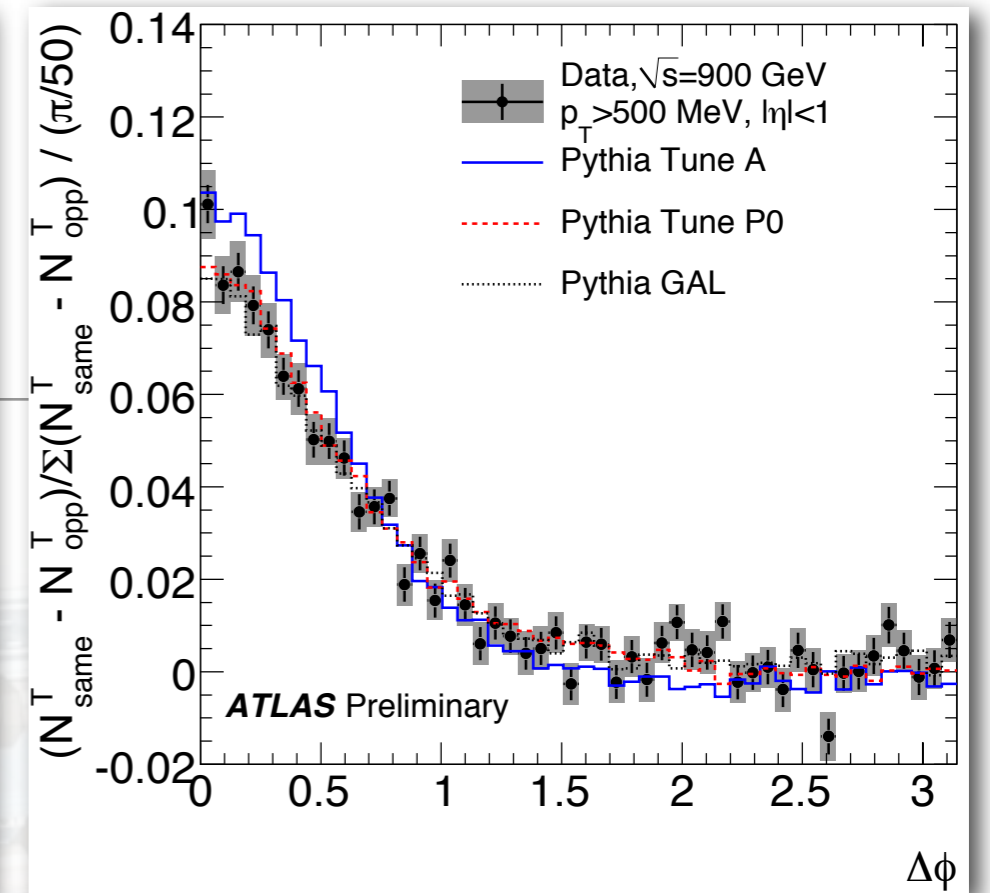
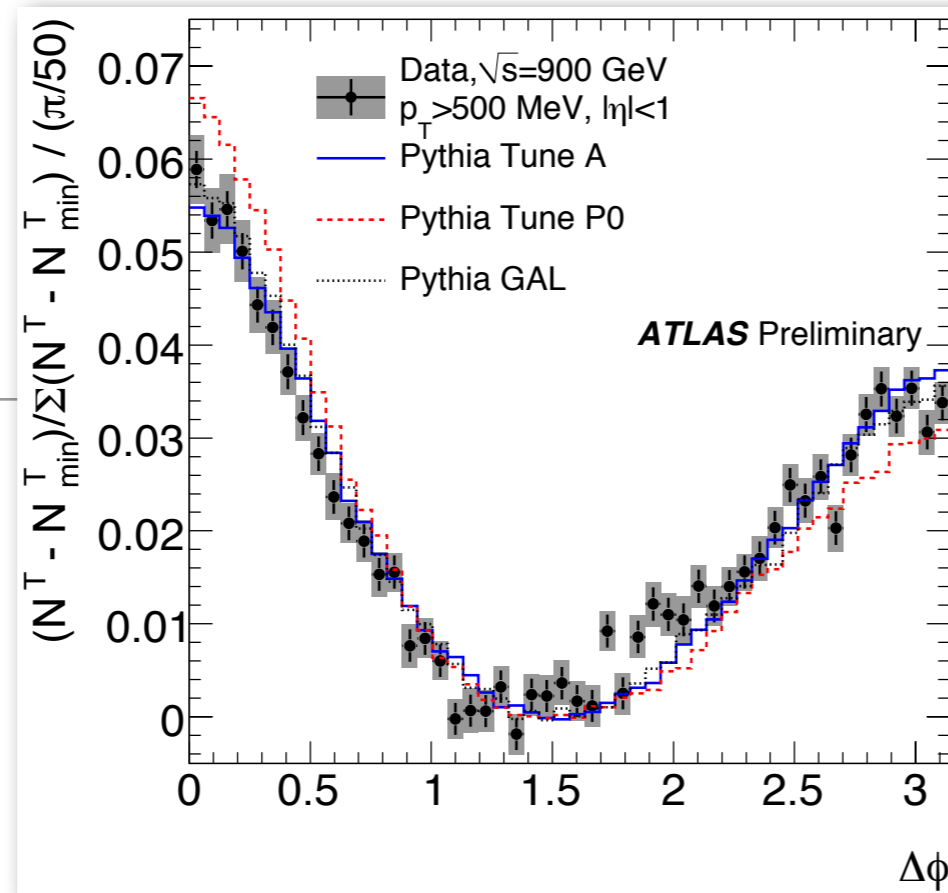


$p_T > 500$ MeV
 $|\eta| < 2.5$



Even though the MC models used in this comparison cover a large range of possible behaviours, none of them match the data well.

Results



Better agreement in the region $|\eta| < 1.0$. Not surprising as most of the tunes use CDF data as input.